

# **Synthesis of zinc titanate for Dye Sensitized Solar Cell (DSSC) application**

by

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10368

Dissertation submitted in partial fulfillment of  
the requirements for the  
Bachelor of Engineering (Hons)  
(Chemical Engineering)

Supervisor : Assoc. Prof. Dr. Anita Ramli.

Jan 2010

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## **CERTIFICATION OF APPROVAL**

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Approved by:

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Assoc. Prof. Dr. Anita Ramli

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AZMAN BIN AZUMI

## **ABSTRACT**

The objectives of the project are to synthesis zinc titanate and characterize the structure for Dye Sensitized Solar Cells (DCCS) application. The porous structure of zinc titanate will increase the light absorption at the longer wavelength of sunlight and increase the efficiency of the DSSC system.

Currently, intensive research was done by researcher to increase the efficiency of DSSCs system so that it can be used in industrial scale. There are many factors that effect the efficiency of DSSCs system and one of it is the characteristic of electrode used. The parameters such the surface area, porosity, crystalline grains, and rate of recombination of photoinduced electrone are important in determining the efficiency of DSSCs system.

In this project, zinc titanate will be synthesis by two methods that are reflux and impregnation method. The composition of the reactant will be varies to prepare different sample of zinc titanate. The characteristic zinc titanate structure will be tested to identify the best compositon in producing zinc titanate that can be applied in DSSC system. The zinc titanate produced will be tested by using x-ray diffusion (XRD), FTIR, UV-vis, scanning electron microscopy (SEM), and BET analysis. After that, the sample of zinc titanate will be tested in the test cells to determine the electricity generation.

Most of the researcher found that the most favorable temperature to synthesis zinc titanate is between 800°C to 945°C. The amount of zinc also needs to be less than titanium to keep the efficiency of DSSCs system high.

## **ACKNOWLEDGEMENT**

First and foremost, thank to God for His blessing and mercy in completing this one year project. It would befit to extend my outstretched gratitude to Assoc. Professor Dr. Anita Ramli, Fundamental and Applied Sciences Department, Universiti Teknologi Petronas. It is a privilege to be under her supervision. Even with her tight schedules as Head of Department and high commitment to Universiti Teknologi Petronas, there was no moment where she fails to provide support and guidance. Her advices and moral support gave a sense of strength and confidence in conducting the final year project.

Many thank to our Final Year Project Coordinators, for their unlimited contributions success in providing the students with guidelines and seminars to enlighten hopes of confidence. Not forget to thank all lab executive and technicians as their willingness to provide the facilities and entertain our demand during conducting the project.

Last but not least, thank to all the Universiti Teknologi Petronas involved lecturers and students who have been contributing great efforts and ideas making this final year project a success.

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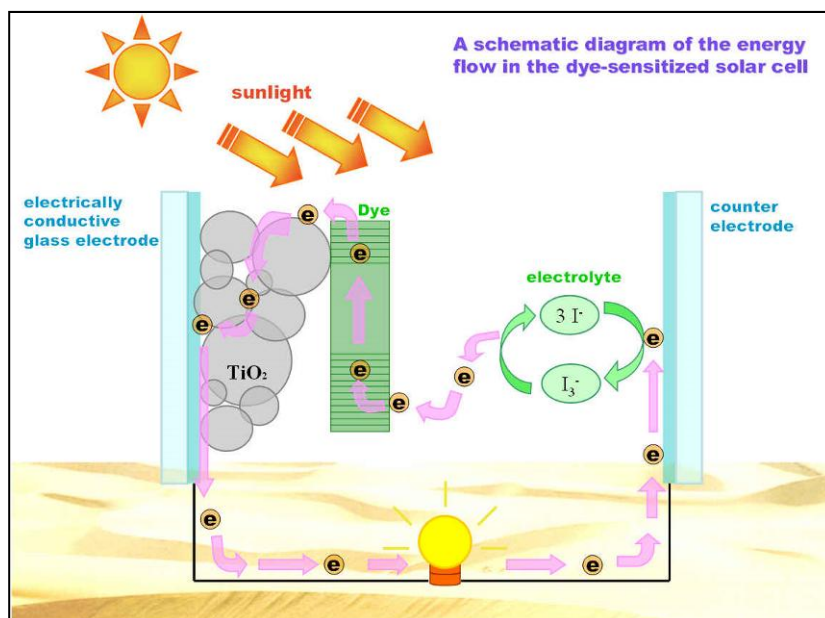
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# CHAPTER 1

## INTRODUCTION

### 1.1 Background of study

Solar cell is a device that converts the light into electrical energy in photovoltaic energy conversion. However the high cost of solar cell has remained a limiting factor for the implementation of solar electricity in a large scale. Recently, the general trend of nanotechnology emerged in the field of photovoltaic energy conversion. Development of material in nanometer scale has generated new photovoltaic materials and systems that could potentially lead to realization of low-cost solar cells in the future. The most well known photovoltaic system is the dye-sensitized nanostructured solar cell (DSSC) developed by Grätzel (Grätzel 1991).



**Figure 1.1:** The flow of electron in DSSC system

When the DSSC is illuminated with sunlight, the dye will absorb the light and becomes excited. The excited dye inject electron to the conduction band of semiconductor. At the same time, the oxidize dye is reduced by electron donor and returns to ground state. The electrons in the conduction band are collected at the counter electrode and flow through the external circuit.



## 1.2 Problem statement

The solar spectrum has a large photon flux in the wavelength region 500–1,000 nm, and a good overlap of the optical absorption spectrum of the sensitizer with the solar spectrum is helpful to achieve higher performance of the DSSC. To enhance light absorption or extending the spectral response to the wavelength, employing light scattering structures such as some metal oxide particles with several hundred nanometers in diameter or admixture of some larger particles to increase the average optical path length of the light within the film. Employing these scattering structures will enhance photocurrent by increasing the light absorption at longer wavelength region ( $600 < \lambda < 800$  nm).

Currently, the highest efficiency electrode in DSSC system is titanium dioxide ( $\text{TiO}_2$ ). However, this electrode only caters for visible light that have wavelength range from 400nm to 700nm. By hybridization of  $\text{TiO}_2$  and  $\text{ZnO}$ , it will produce more spacious band gap. The wide gap provides more porous structure and space for the light absorption to occur as it not only caters for visible light, but also the diffuse light.

$\text{ZnO}$  is selected because of the properties of that structure that have electron mobility higher than  $\text{TiO}_2$ . Even though the band gap of  $\text{TiO}_2$  and  $\text{ZnO}$  is very similar,  $\text{TiO}_2$  have indirect band gap and  $\text{ZnO}$  have direct band gap. It has high exciton binding energy 60meV, and gives a higher resistance for thermally induce exciton recombination (Soga, 2006, p.231).

## 1.3 Objectives

- To synthesis zinc titanate by using impregnation and reflux method
- To characterize the zinc titanate.
- To determine the best composition ratio that gives the optimum structure of the zinc titanate nanocrystal.
- To determine the efficiency of the zinc titanate nanostructure in DSSCs system.

#### **1.4 Scope of study**

This research project is carried out to synthesis zinc titanate that will provide more porous structure of nanohybrid electrode. The parameters that will be study in this research are the method to synthesis zinc titanate and the effects of composition.

The zinc titanate produced then will be characterized by using x-ray diffraction (XRD), UV-vis analysis, FTIR, surface area analysis by using BET technique, and scanning electron microscope (SEM). After that, the zinc titanate will be integrated into a test cell to determine the effect of the sample in electricity generation. The amount of electricity generated will be compared to determine the best method and composition that increase the efficiency of DSSCs system as compare to  $\text{TiO}_2$  electrode only.

This project is relevant enough as it cover on the preparation of the zinc titanate nanostructured material, characterization of sample produced and sample performance test. This project is feasible as it can be done within the time frame if there is no delay on chemical order and equipment failure.

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## **CHAPTER 2**

### **LITERATURE REVIEW**

DSSC technology gives a large flexibility in the choice of the components allowing the ability to fine-tune the properties of the solar cell. The choice of metal oxide for the nanostructures electrode will affect the range of band gap, band edge positions, the density of states and the electron transport and loss properties. The choice will also affect the possibility to obtain different shapes and doping densities of the nanoparticles. For each choice of oxide material the particle size, the surface structure and the porosity and film thickness are also important parameters to optimize for each type of sensitizing dye and redox system.

At present, nanostructure  $\text{TiO}_2$  was used as the electrode for DSSC system. The electrode has huge surface area per projected area that can drastically increase effective light absorption. The current highest energy conversion efficiency is over 11% and it's possible to increase the efficiency of this DSSC by manipulating the structure of electrode (Soga, 2006, p.193).

Hua Yu et al. (2009) has synthesis  $\text{TiO}_2$  organic sol for the preparation of a compact  $\text{TiO}_2$  layer on fluorine-doped tin oxide (FTO) glass by a dip-coating technique. The resultant thin film was used for the fabrication of DSSCs. The compact layer typically has a thickness of ca. 110 nm as indicated by its SEM, and consists of anatase as confirmed by the XRD pattern. Compared with the traditional DSSCs without this compact layer, the solar energy-to-electricity conversion efficiency, short-circuit current and open-circuit potential of the DSSCs with the compact layer were improved by 33.3%, 20.3%, and 10.2%, respectively. This can be attributed to the merits brought by the compact layer. It can effectively improve adherence of  $\text{TiO}_2$  to FTO surface, provide a larger  $\text{TiO}_2$ /FTO contact area, and reduce the electron recombination by blocking the direct contact between the redox electrolyte and the conductive FTO surface.

Yanan Fu and co-worker have synthesized  $\text{TiO}_2$  synthesized by sol–gel route using poly (alkylene oxide) block copolymer as template and tetrabutyl orthotitanate as titanium source. They investigate the influence of acetylacetone (AcAc), glacial acetic acid, HCl and AcAc-HCl as inhibitors on hydrolysis/condensation reaction. The mesopore structure, crystalline phase and optical characteristics were analyzed by  $\text{N}_2$  adsorption, X-ray diffraction, transmission electron microscopy and UV–VIS–NIR spectrum. Photoaction measurements were performed on dye-sensitized solar cells (DSSCs) using the mesoporous  $\text{TiO}_2$  as photoanodes. They found that the formed films are anatase phase and mesoporous structure. Different restraining mechanisms of these inhibitors to hydrolysis/condensation process lead to different mesoporous structure whose specific surface area (BET) varies from 34 to 176  $\text{m}^2/\text{g}$ , and crystal size is from 5.6 to 38.2 nm. The mesoporous photoanode with high BET and large crystalline grains will increase the conversion efficiency of the DSSCs system.

Seok-Soon Kim and co-researcher examined the method for preparing a flexible dye-sensitized solar cell for commercial competitiveness of a DSSC and fabricate a new photoelectrode using ZnO coated  $\text{TiO}_2$  nanoparticles to provide an inherent energy barrier at the electrode/electrolyte interface leading to a reduced recombination of photoinduced electrons. The cell performance was compared through I–V curve and wavelength dependent photocurrent measurements of the two types of DSSC. The value of short-circuit current density, voltage, fill factor, and overall conversion efficiency increased from 0.35 to 0.49  $\text{mA}/\text{cm}^2$ , from  $-0.67$  to  $-0.72\text{V}$ , from 61.1 to 69.0%, and from 0.71 to 1.21%, respectively without any post-treatments.

Mingdeng Wei et al. (2006) found a high light-to-electricity conversion efficiency of 10% by applying mesoporous  $\text{TiO}_2$  as an electrode material. This high efficiency can be attributed to the novel physicochemical properties of mesoporous  $\text{TiO}_2$ , which include high surface area, uniform nanochannels and a homogeneous nanocrystalline  $\text{TiO}_2$  several nm in size arranged along the framework. The high surface area allows adsorption of a large volume of dye, resulting in a higher photocurrent density.

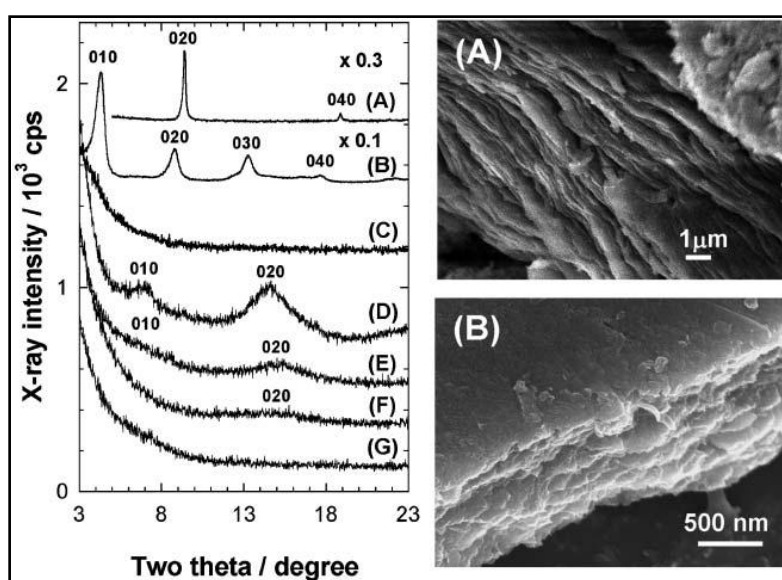
ZnO also is an attractive material that can be used as electrode as it has wide-band gap semiconductor with good carrier mobility. The electron mobility in ZnO is much higher than TiO<sub>2</sub>. However, the chemical stability of ZnO is less than TiO<sub>2</sub> that can cause problems in the dye adsorption procedure. The efficiency of ZnO solar cells so far significantly lower than TiO<sub>2</sub> which is 4-5% (Soga, 2006, p.227-228). ZnO nanomaterials are expected to form energy barriers at the electrode-electrolyte interface because the conduction band edge of ZnO (100 mV) is more negative than that of TiO<sub>2</sub> (B.Posters et al. 2008).

Sang Pang et al. (2007) has conducted a research on the effect of ZnO nanorodes on the efficiency of TiO<sub>2</sub> DSSC system. They found that the solar conversion efficiency of the DSSCs after the addition of ZnO nanorods (1 wt %) was increased by about 15% compared to that without ZnO nanorods. They highlight that first, charge effective diffusion and the suppression of recombination are the origin for the enhancement of voltage and fill factor; second, the shift of the conduction band edge position in the TiO<sub>2</sub>/ZnO electrodes is proposed as the main cause of the enhancement of voltage.

K. E. Kim and co-researcher (2007) found that ZnO-covered TiO<sub>2</sub> film electrode enables enhancement of short-circuit photocurrent density, open-circuit voltage and consequently solar conversion efficiency for a DSSCs by 12%, 17%. And 23% respectively, compared to those of bare TiO<sub>2</sub> electrode system.

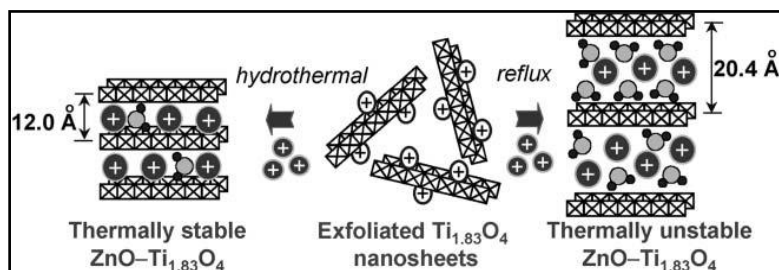
J.H. Hyung et al. (2009) found that covered TiO<sub>2</sub> electrodes with ZnO nanowire will improve the photovoltaic properties of DSSCs or in other word, increase the efficiency of the system. The ZnO nanowires were grown on the surface of a TiO<sub>2</sub> thin-film electrode with zinc dehydrate acetate seeds by using thermal chemical vapor deposition. The covered electrode improved the open-circuit voltage and the fill factor while significantly decreasing the short-circuit current density and photovoltaic performance of the covered electrode compared to bare TiO<sub>2</sub> electrode. The current and fill factor of the covered electrode were enhanced by about 10-15% compared with bare TiO<sub>2</sub> electrode system.

Tae Woo Kim and co-workers have synthesized mesoporous nanohybrids interstratified with zinc oxide nanoparticles and layered titanate nanosheets by exfoliation-restaking method. They also found that the lattice stability of the resulting nanohybrids could be greatly enhanced by hydrothermal treatment. The fitting analysis based on BET equation gives  $\text{ZnO-Ti}_{1.83}\text{O}_4$  by hydrothermal treatment and its calcined derivatives expanded surface areas of 114 and 119–134  $\text{m}^2\text{g}^{-1}$  respectively. The structures properties of  $\text{ZnO-Ti}_{1.83}\text{O}_4$  were characterized by x-ray diffraction (XRD). The result for XRD analysis is tabulated in Figure 1.



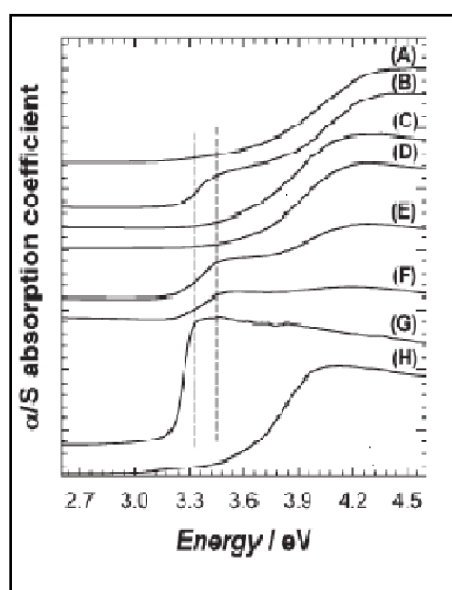
**Figure 2.1:** Left panel: small angle XRD patterns of (A) the protonic titanate, (B)  $\text{ZnO-Ti}_{1.83}\text{O}_4$  by reflux treatment and (C) its derivative calcined at 200 uC, (D)  $\text{ZnO-Ti}_{1.83}\text{O}_4$  by hydrothermal treatment and its derivatives calcined at (E) 200, (F) 300, and (G) 400 uC. Each pattern is shifted along the y-axis for clarity. Right panel: FE-SEM (field emission scanning electron microscopy) images of (A)  $\text{ZnO-Ti}_{1.83}\text{O}_4$  by reflux treatment and (B)  $\text{ZnO-Ti}_{1.83}\text{O}_4$  hydrothermal treatment.

After heat-treatment at 200°C,  $\text{ZnO-Ti}_{1.83}\text{O}_4$  by reflux treatment shows complete disappearance of (010) reflections indicate that the disintercalation of the guest species and the formation of ZnO on the sample surface. On the other hand, the calcined derivative  $\text{ZnO-Ti}_{1.83}\text{O}_4$  by hydrothermal treatment at 200°C retain series of (010) reflections without the appearance of ZnO peaks. The heat-treatment at 400°C can completely remove (010) peaks as well as to the development of weak ZnO peaks at high angle region.



**Figure 2.2:** Dependence of crystal structure and thermal stability of porous zinc oxide-layered titanate nanohybrids on the synthetic conditions.

From the least squares fitting analysis, they find that the basal spacing is 20.4Å for the zinc titanate by reflux treatment and 20.0Å by hydrothermal treatment. This finding prove that the effectiveness of hydrothermal method in improving the heterostructure stability.



**Figure 2.3:** Diffuse reflectance UV-vis spectra of (A) ZnO–Ti<sub>1.83</sub>O<sub>4</sub>-R and (B) its derivative calcined at 200 uC, (C) ZnO–Ti<sub>1.83</sub>O<sub>4</sub>-H and its derivatives calcined at (D) 200, (E) 300, and (F) 400 uC, together with the reference spectra of (G) ZnO and (H) Cs<sub>0.67</sub>Ti<sub>1.83</sub>O<sub>4</sub>. Each spectrum is shifted along the y-axis for clarity. The dashed lines are guidelines for easier interpretation of the figure.

UV-vis analysis gives the zinc titanate nanohybrids 3.6-3.7 eV that are greater than ZnO (3.2 eV) due to the quantum confinement effect of hybridized ZnO species. During calcinations, at 200°C, no detectable change occurs in the UV-vis spectrum of ZnO–Ti<sub>1.83</sub>O<sub>4</sub> by hydrothermal treatment, while calcined derivative by reflux treatment shows appearance of a new absorption edge at ~ 3.3 eV; indicate the formation of ZnO on the sample surface.

N. Labus and co-researchers are using the most common way for obtaining metatitanate  $\text{ZnTiO}_3$  that is the sol-gel method. This method provides fine and homogeneous  $\text{ZnTiO}_3$  particles with a high specific surface area. Because of the diffusion path is reduced, the temperature needed for synthesis in the subsequent treatment is lowered. The low temperature is required for the formation of  $\text{ZnTiO}_3$  because of the decomposition of  $\text{ZnTiO}_3$  to  $\text{Zn}_2\text{TiO}_4$  and rutile at  $945^\circ\text{C}$ .

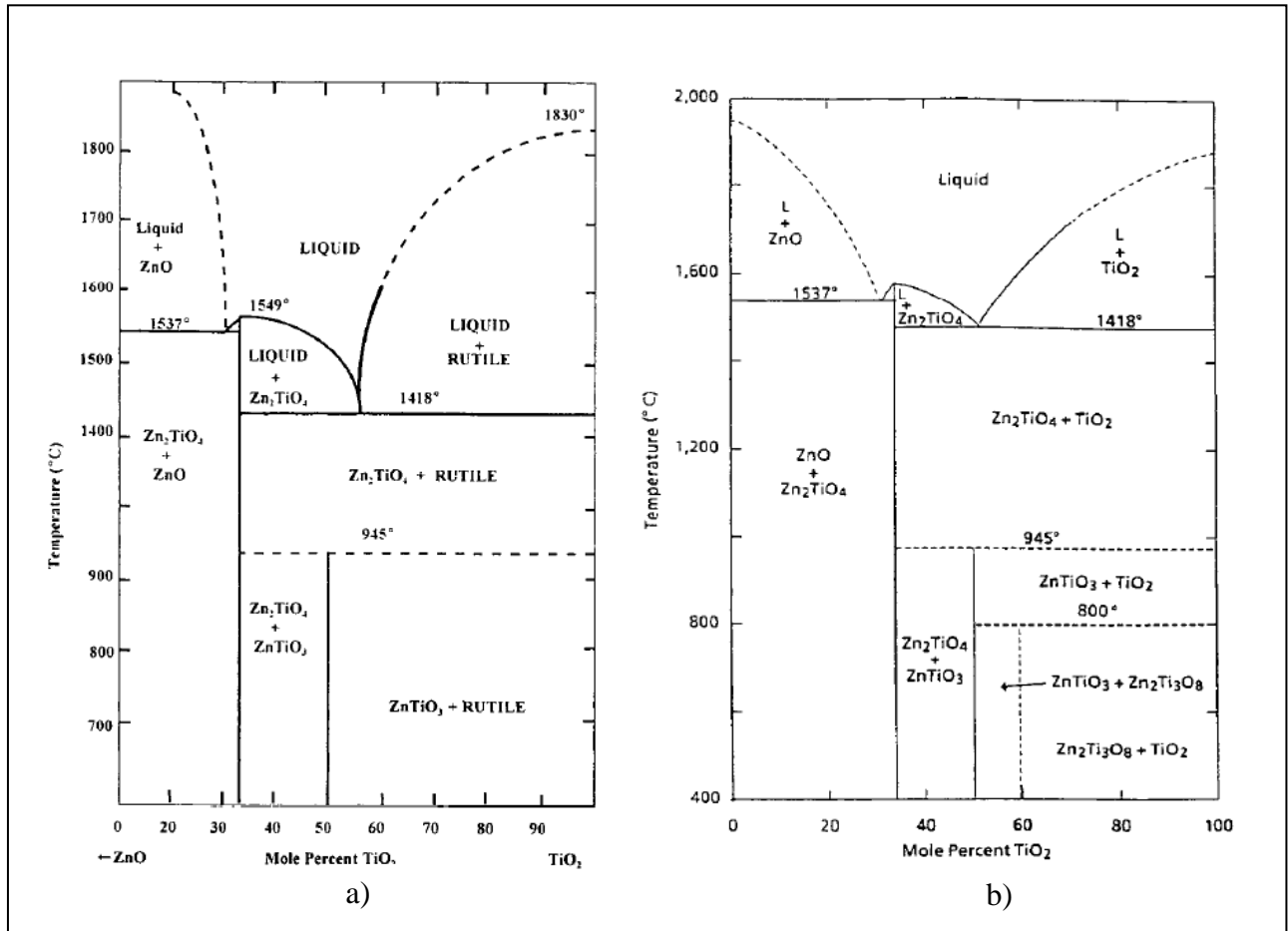
Yamaguchi et al. (1987) clarified that  $\text{Zn}_2\text{Ti}_3\text{O}_8$  is a low-temperature form of  $\text{ZnTiO}_3$ .  $\text{Zn}_2\text{TiO}_4$  can easily be prepared by conventional solid-state reaction between 2  $\text{ZnO}$  and 1  $\text{TiO}_2$ . But, the preparation of pure  $\text{ZnTiO}_3$  from mixture of 1  $\text{ZnO}$  and 1  $\text{TiO}_2$  has not been successful because the compound decomposes into  $\text{Zn}_2\text{TiO}_4$  and rutile at about  $945^\circ\text{C}$  as mention above by N. Labus et al (2005).

Chang et al. (2002) highlight that the properties of materials depend on their synthesis processes, for  $\text{ZnTiO}_3$ , its physical-chemical properties are influences by the synthesizing conditions. The solid-state reaction method has some drawbacks of high temperature, large particle size and limited degree of chemical homogeneity. In contrast, the chemical solution methods such sol-gel method can provide products of fine and homogeneous particles with high specific surface area. The Pechini method is a conventional approach to prepare powder consisting of oxides of transition element. They prepare  $\text{ZnTiO}_3$  powders by sol-gel method by using zinc acetate, ethylene glycol, titanium butoxide, and citric acid anhydrous and found that the crystallinity of  $\text{ZnTiO}_3$  powders increase with increasing calcinations temperature and times, and the best conditions for calcinations is  $800^\circ\text{C}$  for 10 hours. The morphology of  $\text{ZnTiO}_3$  powders formed fiber type when calcinations temperature increased to  $1000^\circ\text{C}$  and the grain size from the research were about 20 to 40nm.

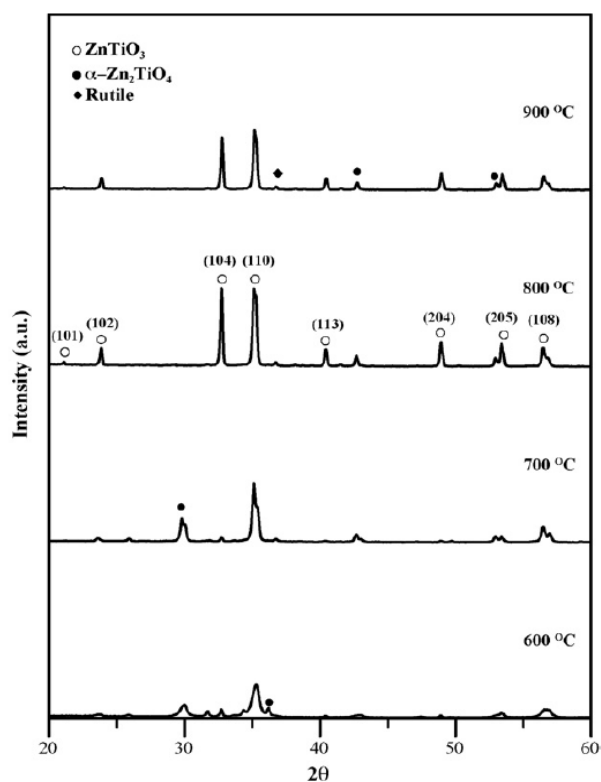
J. Yang and J.H. Swisher has conducted a research to study the phase stability of  $\text{Zn}_2\text{TiO}_8$ . Several types of experiments were carried out to obtain additional information on  $\text{ZnO-TiO}_2$  phase diagram and they found that  $\text{Zn}_2\text{Ti}_3\text{O}_8$  is a thermodynamically stable compound up to a temperature of  $800^\circ\text{C}$ . Above than that, it will transforms sequentially into  $\text{ZnTiO}_3$  and then into  $\text{Zn}_2\text{TiO}_4$ . The new  $\text{ZnO-TiO}_2$  phase diagram is shown in Figure 5 as comparison to the previous phase diagram introduced by Dulin and Rase in 1960.



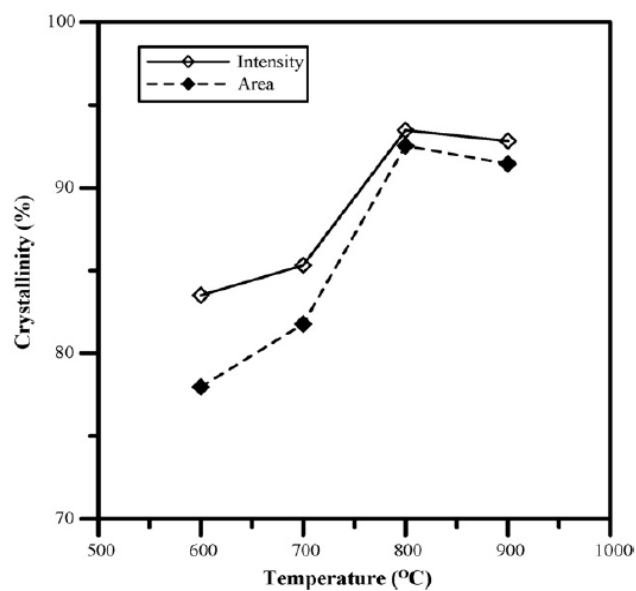
Chai et al. (2007) has study the effects of heat treatment on the structure of zinc titanate prepared by Pechini process. The steps involve in heating process including dehydration reaction, decomposition, combustion reaction and zinc titanate formation. The crstallinity of zinc titanate have been improved by increasing the calcinations temperature. The optimum temperature for calcinations is at 800°C for 6 hours. The microstructures of zinc titanate have been validated using transmission electron microscopy (TEM) and the grain sizes are shown to vary between 20nm and 50nm. The x-ray diffusion (XRD) profiles with different calcinations temperature are shown in Figure 6 and the crystallinity of zinc titanate with respect to temperature is shown in Figure 7. Both of the figures prove that the best temperature to synthesis zinc titanate is at 800°C.



**Figure 2.4:** a) ZnO-TiO<sub>2</sub> phase diagram published by Dulin and Rase in 1960, b) Proposed new ZnO-TiO<sub>2</sub> phase diagram by J. Yang and J.H. Swisher in 1996.



**Figure 2.5:** XRD profiles of ZnTiO<sub>3</sub> powders derived from ZnTiO<sub>3</sub> precursor solution after heat-treatment at different temperatures for 6 hours.

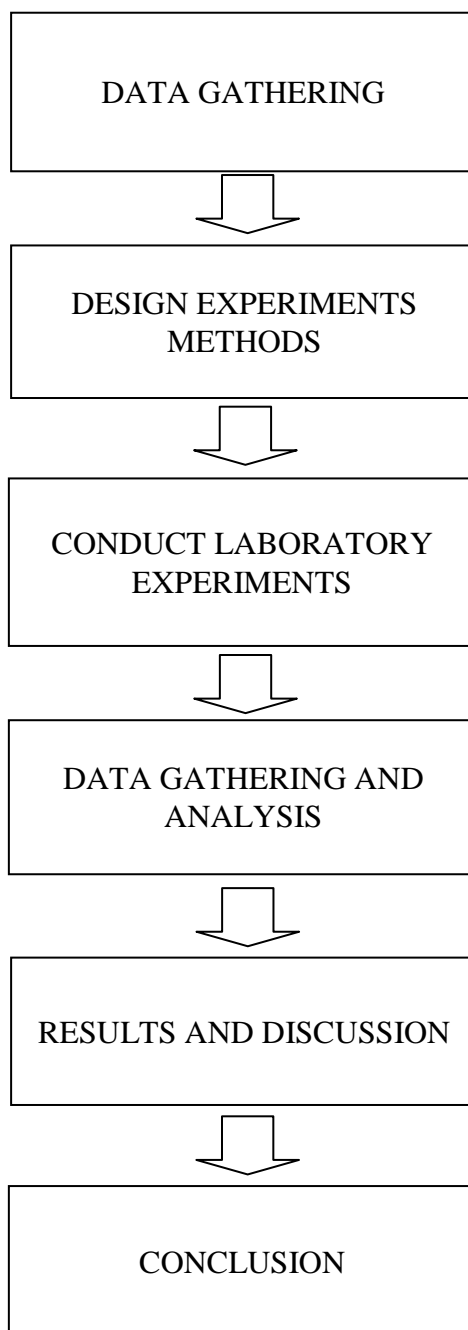


**Figure 2.6:** Crystallinity of ZnTiO<sub>3</sub> precursor solution after heat-treated at various temperatures for 6 hours.

## CHAPTER 3

### METHODOLOGY

#### 3.1 Project Flow



**Figure 3.1:** Project Process Flow

### **3.2 Sample preparation**

#### Method 1: Reflux treatment

Zinc titanate was prepared by first dissolving 1 mol of zinc nitrate with distilled water in a beaker and adds 1 mol of titanium oxide into the solution. The mixture is then stirred for 30 minutes to get well distribution of titanium dioxide in the solution. After that, the mixture is reflux for 5 hours by using heating mantel at its boiling point temperature. Then, transfer the mixture from one-neck flask into a beaker and put it in the drying oven for 120°C overnight. The purpose of drying sample at 120°C is to make sure that all the water is vaporized and removed from the sample. Next, is to calcine the samples in the furnace for 5 hours at 500°C to remove the entire nitrate group in the samples. The experiment was repeated for 2 to 1 and 1 to 2 mol ratio of zinc to titanium.

#### Method 2: Impregnation

For the second method in getting zinc titanate, weight about 5% of zinc from the final weight (approximately 14.5g zinc nitrate for 100g sample). The solution is then added with remaining 95% titanium dioxide. After that, the mixture is stirred for 5 hours by using magnetic stirrer at 500 rpm. Then, the sample is dried in the drying oven at 120°C for one night. Next, the sample is calcine in the furnace at temperature 500°C for 5 hours as to remove the entire nitrate group in the mixture. The experiment was repeated for 10% and 15% amount of zinc in the sample.

### 3.2 Milestone for Final Year Project (FYP) I

| Phases | Detail/Week                                  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|--------|--|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| 1      | Selection of Project Topic                   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
|        | Proposal Submission                          |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
|        | Approval on Proposal                         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
|        | Identification of chemicals                  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 2      | Check Availability of Apparatus              |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 3      | Submission of Preliminary Report             |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 4      | Seminar 1                                    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 5      | Experiment Methodology Identification        |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
|        | Finalize Experimental Methodology            |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 6      | Chemical Assesment and Hazard Identification |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 7      | Submission of Progress Report                |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 8      | Seminar 2                                    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 9      | Submission of Interim Report                 |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 10     | Oral Presentation                            |   |   |   |   |   |   |   |   |   |    |    |    |    |    |

**Figure 3.2:** Milestone for FYP I

### 3.3 Milestone for Final Year Project (FYP) II

| Phases | Detail/Week                     | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|--------|---------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| 1      | Project Work Continue           |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 2      | Submission of Progress Report 1 |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 3      | Project Work Continue           |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 4      | Submission of Progress Report 2 |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 5      | Seminar                         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 6      | Project Work Continue           |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 7      | Poster Presentation             |   |   |   |   |   |   |   |   |   |    |    |    |    |    |
| 8      | Submission of Dissertation      |   |   |   |   |   |   |   |   |   |    |    |    |    |    |

**Figure 3.3:** Milestone for FYP II

### 3.4 Characterization

#### XRD analysis

X-ray scattering techniques are used to reveal information about the crystallographic structure, chemical composition, and physical properties of materials and thin films. These techniques are based on observing the scattered intensity of an X-ray beam hitting a sample as a function of incident and scattered angle, polarization, and wavelength or energy. X-ray diffraction finds the geometry or shape of a molecule using X-rays. X-ray diffraction techniques are based on the elastic scattering of X-rays from structures that have long range order. For diffraction applications, only short wavelength x-rays (hard x-rays) in the range of a few angstroms to 0.1 angstrom (1 keV - 120 keV) are used. Because the wavelength of x-rays is comparable to the size of atoms, they are ideally suited for probing the structural arrangement of atoms and molecules in a wide range of materials. The energetic x-rays can penetrate deep into the materials and provide information about the bulk structure. The wave nature of the X-Rays diffracted by the lattice of the crystal to give a unique pattern of peaks of 'reflections' at differing angles and of different intensity, just as light can be diffracted by a grating of suitably spaced lines. The diffracted beams from atoms in successive planes cancel unless they are in phase, and the condition for this is given by the Bragg relationship;

$$n\lambda = 2 d \sin \Theta$$

Where,

$\lambda$  is the wavelength of the X-Rays

$d$  is the distance between different plane of atoms in the crystal lattice.

$\Theta$  is the angle of diffraction.

### Uv-vis analysis

Ultraviolet-visible spectroscopy or ultraviolet-visible spectrophotometry (UV-Vis or UV/Vis) involves the spectroscopy of photons in the UV-visible region. This means it uses light in the visible and adjacent (near ultraviolet (UV) and near infrared (NIR)) ranges. The absorption in the visible ranges directly affects the color of the chemicals involved. In this region of the electromagnetic spectrum, molecules undergo electronic transitions. This technique is complementary to fluorescence spectroscopy, in that fluorescence deals with transitions from the excited state to the ground state, while absorption measures transitions from the ground state to the excited state.

### Scanning electron microscope (SEM) analysis

SEM is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity. The types of signals produced by an SEM include secondary electrons, back-scattered electrons (BSE), characteristic X-rays, specimen current and transmitted electrons.

### FTIR

Fourier transform infrared (FTIR) spectroscopy is a measurement technique for collecting infrared spectra. Instead of recording the amount of energy absorbed when the frequency of the infra-red light is varied (monochromator), the IR light is guided through an interferometer. After passing through the sample, the measured signal is the interferogram. Performing a Fourier transform on this signal data results in a spectrum identical to that from conventional (dispersive) infrared spectroscopy.



## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 Catalyst characterization

##### 4.1.1 Diffuse Reflectance UV-Vis (DRS)

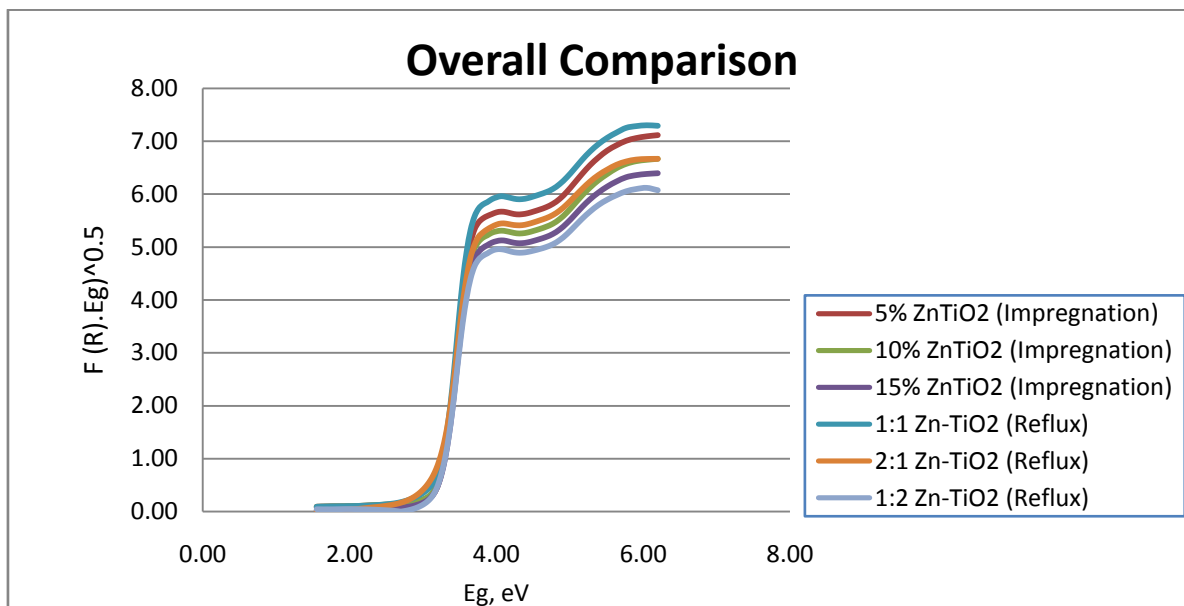


Figure 4.1 : Tauc plot comparison for all samples.

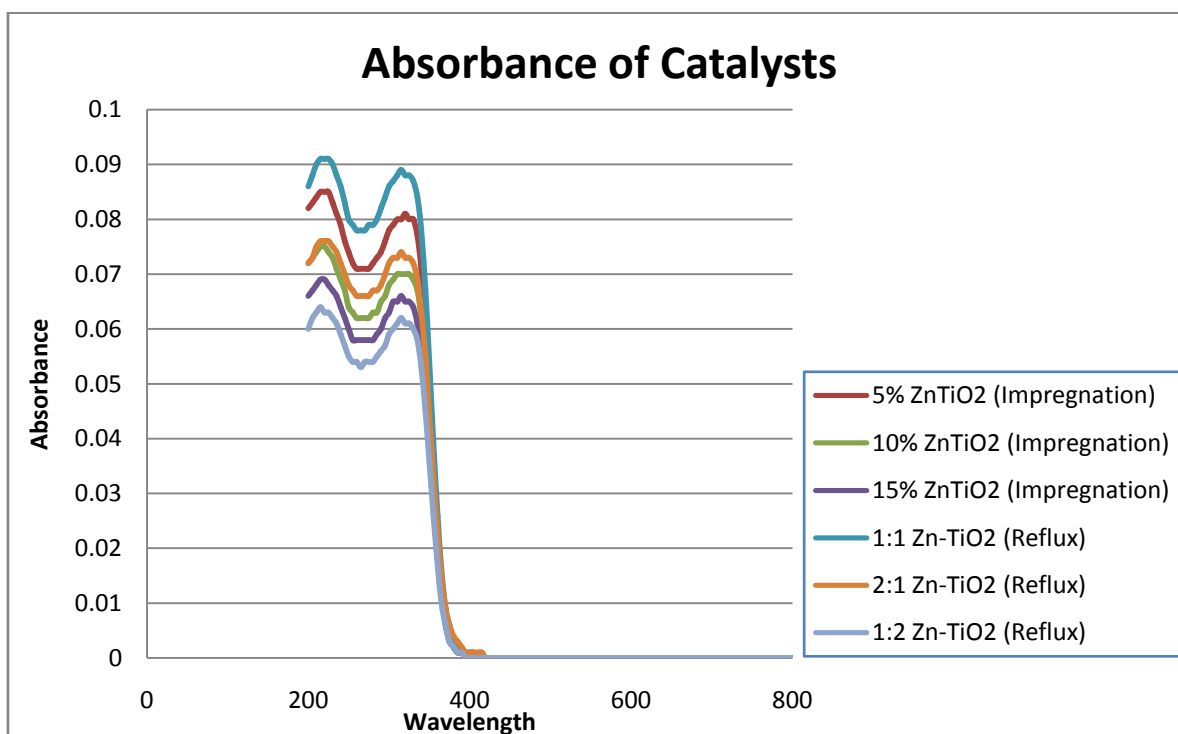


Figure 4.2 : Absorbance of the samples

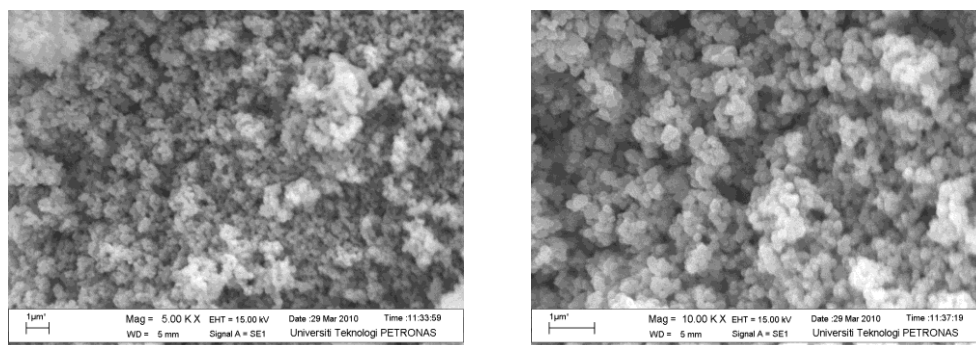
**Table 4.1:** Band gap energy of zinc titanate

| Sample                     | Band gap energy |
|----------------------------|-----------------|
| 5 wt% Zn-TiO <sub>2</sub>  | 3.24            |
| 10 wt% Zn-TiO <sub>2</sub> | 3.25            |
| 15 wt% Zn-TiO <sub>2</sub> | 3.26            |
| 1:1 Zn-TiO <sub>2</sub>    | 3.24            |
| 1:2 Zn-TiO <sub>2</sub>    | 3.22            |
| 2:1 Zn-TiO <sub>2</sub>    | 3.25            |

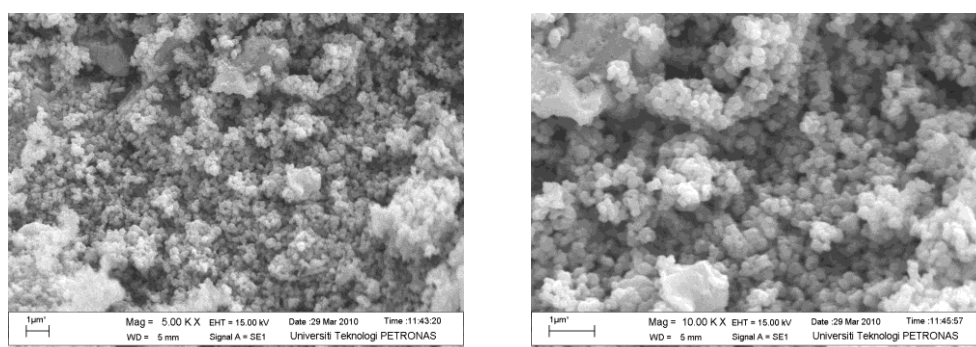
From the experiment, the 15wt% of Zn-TiO<sub>2</sub> by using impregnation method gives the highest value of band gap which is 3.26. The band gap will increase with the increasing amount of zinc in the sample. This is due the higher band gap energy of zinc as compared to titanium dioxide. Both methods show that the band gap of the sample increases with the amount of zinc. The improvement of band gap due to presence of zinc is good to reduce the recombination rate in DSSCs system, but if the amount of zinc is too high it will reduce the total efficiency as compared to bare TiO<sub>2</sub> electrode.

The solar energy conversion efficiency of DSSCs can be improved by the coating of ZnO as ZnO has bigger band gap compare to TiO<sub>2</sub> which is about 3.37 eV. ZnO also has the conduction band edge of (100 mV) more negative than that of TiO<sub>2</sub> as mention earlier by B.Posters et al. (2008). It show that the coating of ZnO on the TiO<sub>2</sub> contributes to provide an inherent energy barrier that suppressed charge recombination and improved voltage generated, resulting in an increase in conversion efficiency as well as fill factor compared to the single TiO<sub>2</sub> as reported by M.C. Kao et al.(2009).

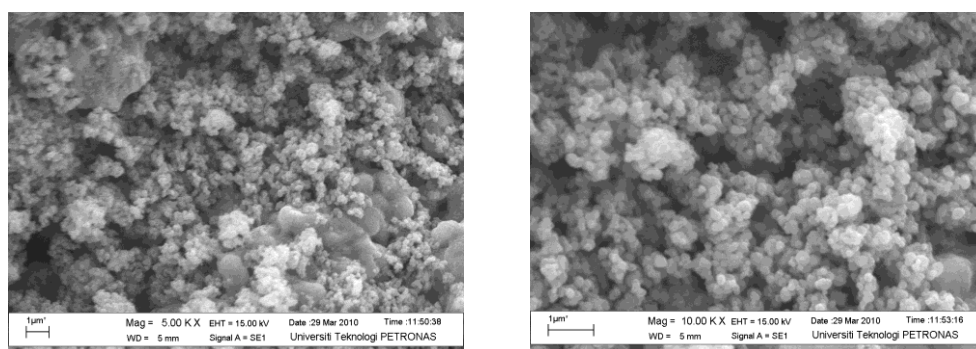
### 4.1.2: Scanning Electron Microscopy (SEM)



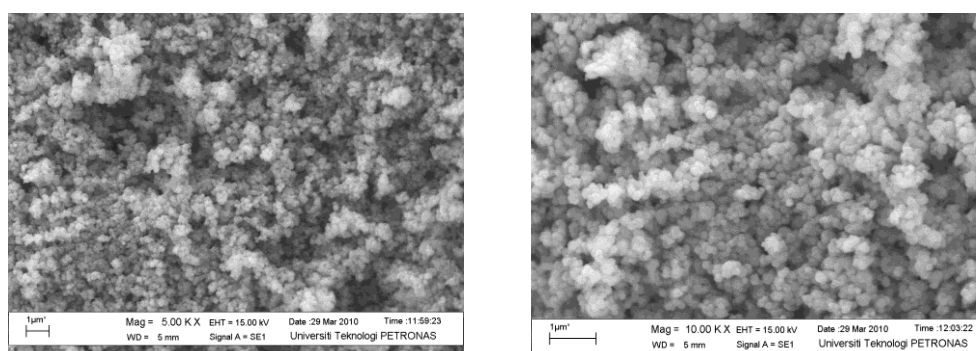
**Figure 4.3:** 1:1 mol ratio Zn-TiO<sub>2</sub>



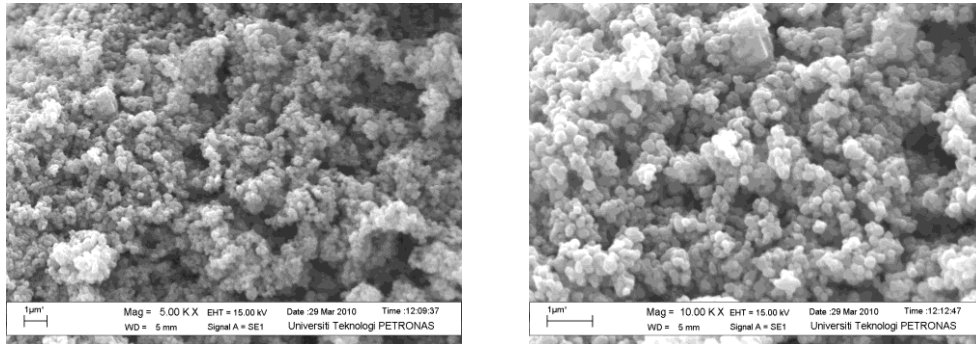
**Figure 4.4:** 1:2 mol ratio Zn-TiO<sub>2</sub>



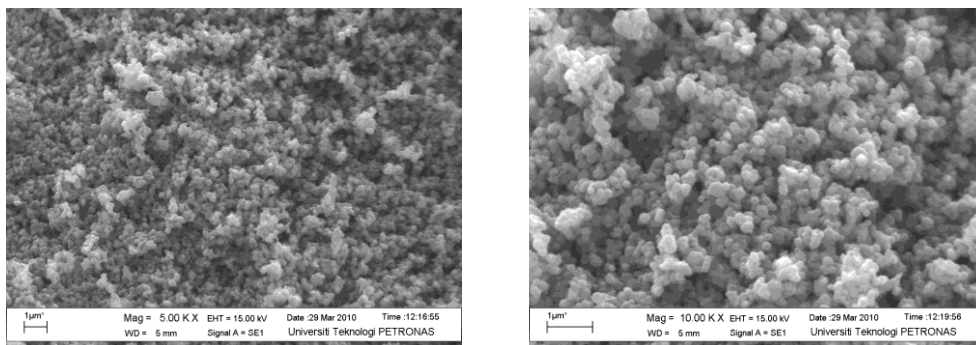
**Figure 4.5:** 2:1 mol ratio Zn-TiO<sub>2</sub>



**Figure 4.6:** 5wt% Zn-TiO<sub>2</sub>



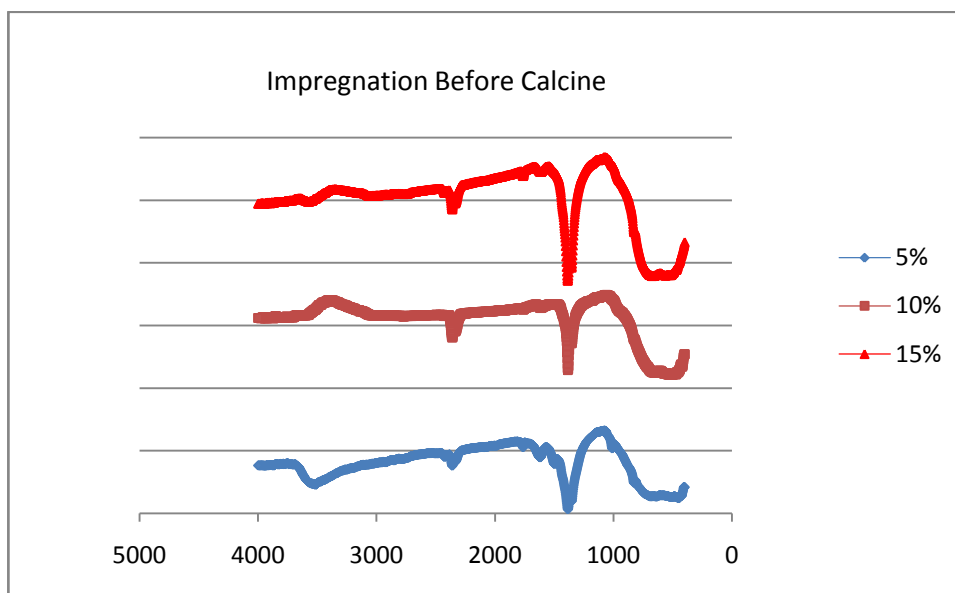
**Figure 4.7: 10wt% Zn-TiO<sub>2</sub>**



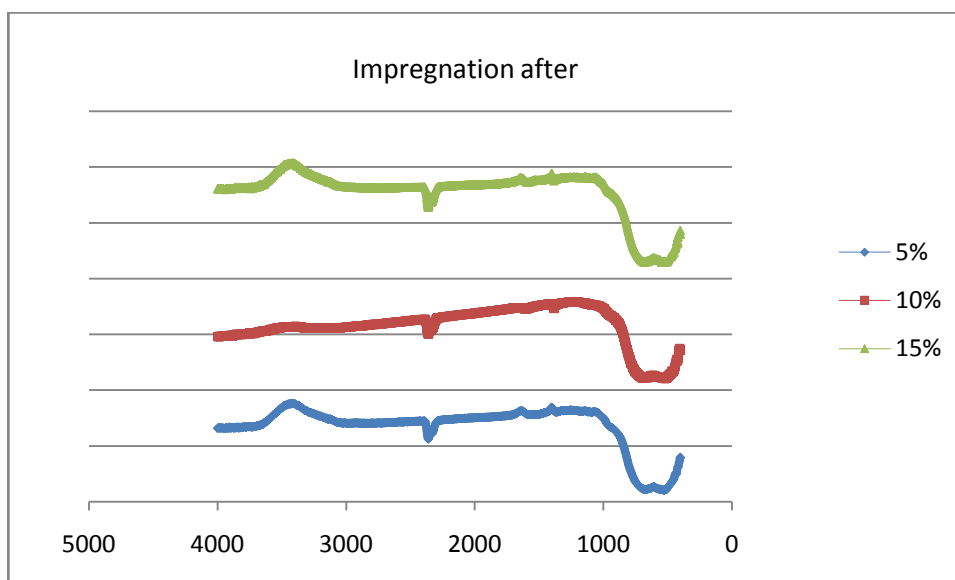
**Figure 4.8: 15wt% Zn-TiO<sub>2</sub>**

Figures 4.3 to 4.8 are pictures taken by SEM on sample of the catalyst. In SEM analysis, the sample will undergo analysis where sample surface is analyzed using an electron. From the data, it shows how the component of the catalyst is distributed on the surface of catalyst. A good catalyst will have a well distributed component on the surface where reaction can take place. The existence zinc also provides more porous structure to the samples. Instead of having only TiO<sub>2</sub> compact structure molecule, zinc will provide more space for high mobility of ion in the DSSCs system. The deposited film from the suspensions of ZnO coated TiO<sub>2</sub> has also moderate porosity and high surface area to which dye molecule could be adsorbed as reported by S.S.Kim et. al. In a simple word, with zinc in the catalyst TiO<sub>2</sub> the efficiency of DSSCs will increases.

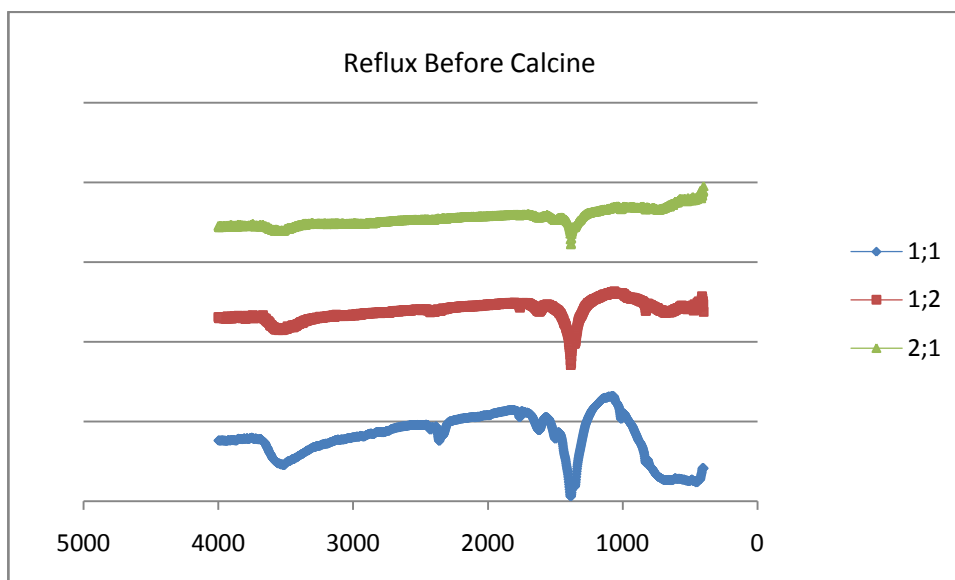
### 4.1.3: Fourier Transform Infrared (FTIR)



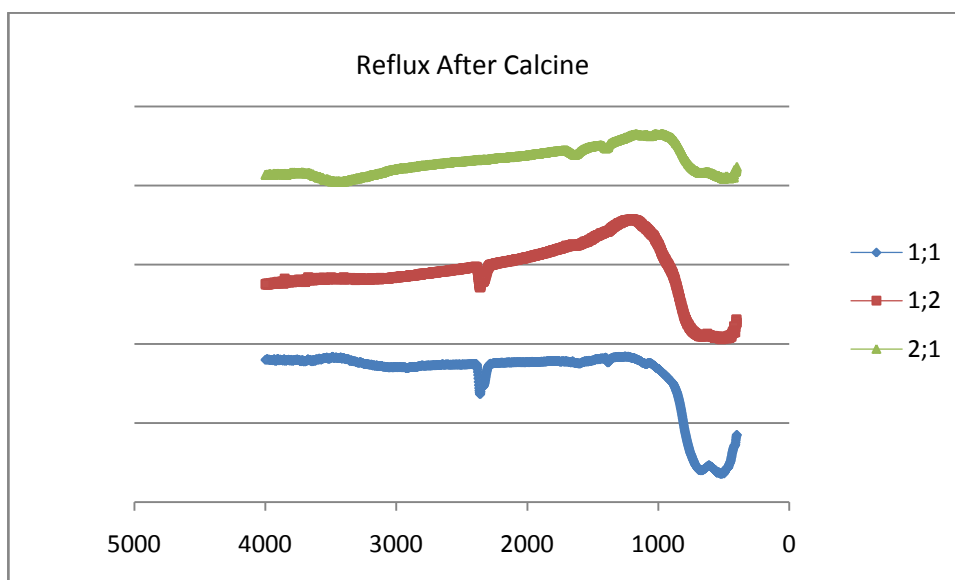
**Figure 4.9:** Impregnation before calcine



**Figure 4.10:** Impregnation after calcine



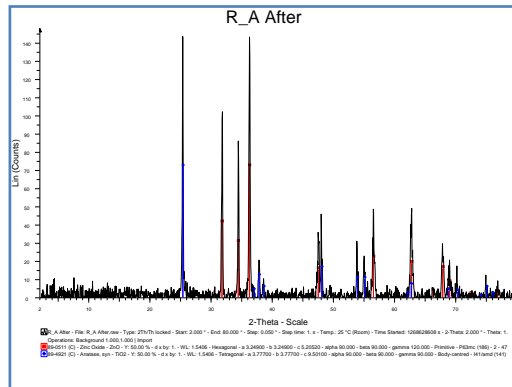
**Figure 4.11:** Reflux before calcine



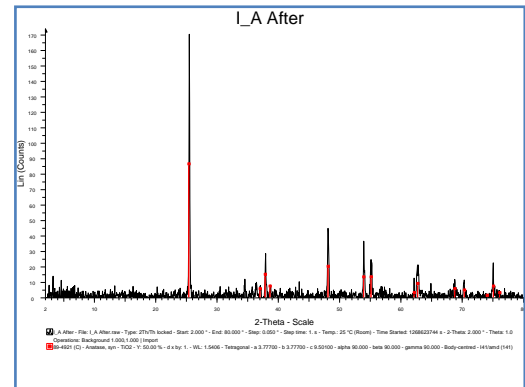
**Figure 4.12:** Reflux after calcine

FTIR results show the bonding in the sample. The absorption peak seen at approximately  $1600\text{cm}^{-1}$  are known to be the O-H bending. As for the broad band seen around  $400 - 900\text{cm}^{-1}$ , that can be attributed to the Ti-O stretching vibrations. Furthermore, absorption peaks around  $1384\text{ cm}^{-1}$  are due to the presence of  $\text{NO}_3$ . These peaks are visible in the spectra before calcinations, but are not present or unclear after calcinations. This goes to show that although nitrate groups were present during the preparation step of the catalysts, they were effectively removed after the calcination process.

#### 4.1.4: X-ray Diffraction (XRD)



**Figure 4.13:** XRD result for reflux sample.



From Figure 4.12, sample A (1:1 mol ratio Zn/TiO<sub>2</sub>) the peak of anatase TiO<sub>2</sub> and ZnO clearly appears as both in the same mol ratio. The highest peak of TiO<sub>2</sub> is at  $2\theta = 25^\circ$  and for ZnO is at  $2\theta = 36^\circ$ . For sample B (2:1 mol ratio Zn/TiO<sub>2</sub>), the ZnO peak is the highest as the mol ratio of zinc to titanium increase. The figure also shows the reduction peak TiO<sub>2</sub> and increasing peak of ZnO. Sample C (1:2 mol ratio Zn/TiO<sub>2</sub>) show the increasing peak of TiO<sub>2</sub> and reduction in ZnO peak. Figure 4.13 show the XRD result for 5%, 10%, and 15% amount of ZnO in TiO<sub>2</sub>. The peak of TiO<sub>2</sub> is reducing as the amount of ZnO increases.



## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

As conclusion, zinc titanate has been produced by using impregnation and reflux method. The catalysts undergo UV-vis analysis and the result shows that the highest band gap can be achieved by using impregnation method with 15% of ZnO in the total sample. From XRD, the anatase phase of  $\text{TiO}_2$  still be maintain and no rutile phase detected. The anatase phase of the catalyst is very important to prevent the recombination rate of dye. FTIR analysis shows the nitrate group in the sample before calcine completely has been removed after calcine at temperature  $500^\circ\text{C}$  for 5 hours. SEM analysis shows the deposited film from the suspensions of ZnO coated  $\text{TiO}_2$  has also moderate porosity and high surface area to which dye molecule could be adsorbed.

In this project, the highest efficiency that has been achieved is 3.26 by using impregnation method with 15 wt% zinc in the sample. Impregnation gives more time for the zinc nitrate and titanium oxide to mix well by continuously stirring the mixture for 5 hours. More time will provide finer tune catalyst. It's suggested that more sample to be produced so that the optimum ratio ZnO to  $\text{TiO}_2$  can be determined. The calcinations temperature also can be varied to see the effect of calcinations temperature to the catalyst.

The limitation of equipment and chemical is one of the marvel problems in conducting final year project. Even it's the creativity of supervisor and student to deal with it, but the first objective of the project normally changed. The equipment seems to be there in lab but when the students want to use it, it already breakdown. So it's suggested that the equipment should be maintain or repair before the new coming semester as the student need it in completing the project. It will drag time and sometimes give difficulties to student in finishing their project.

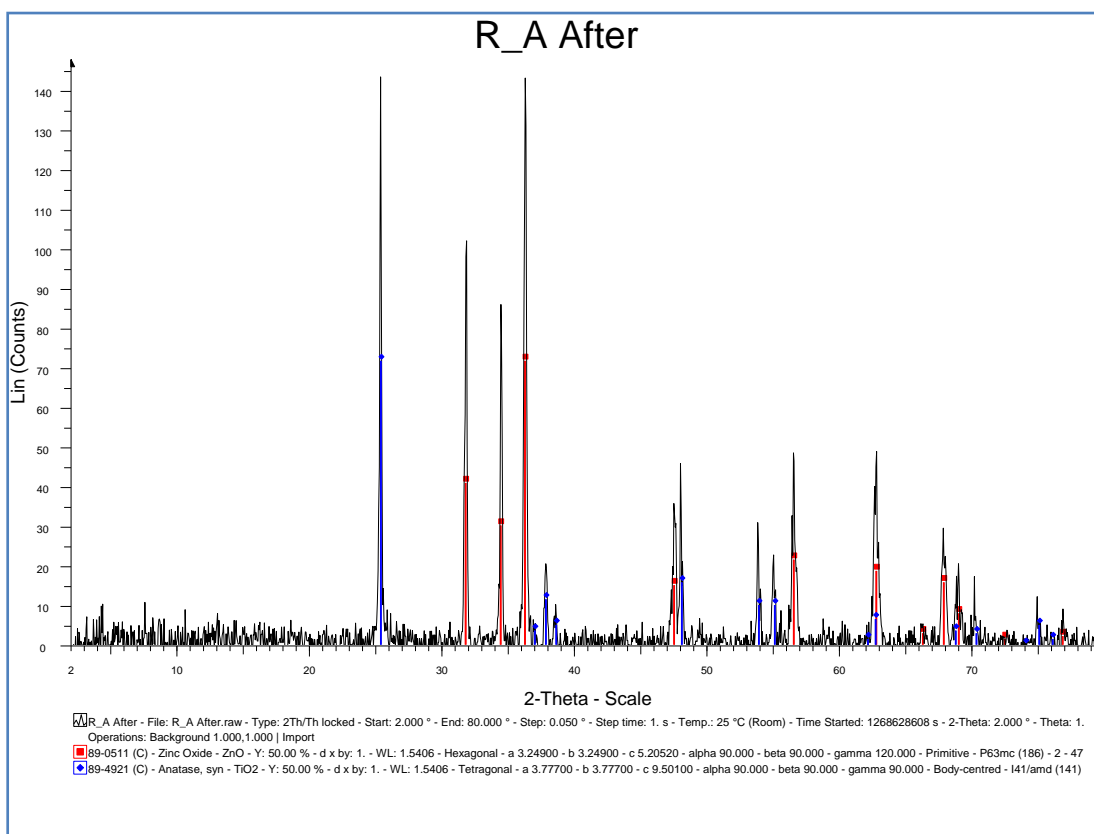
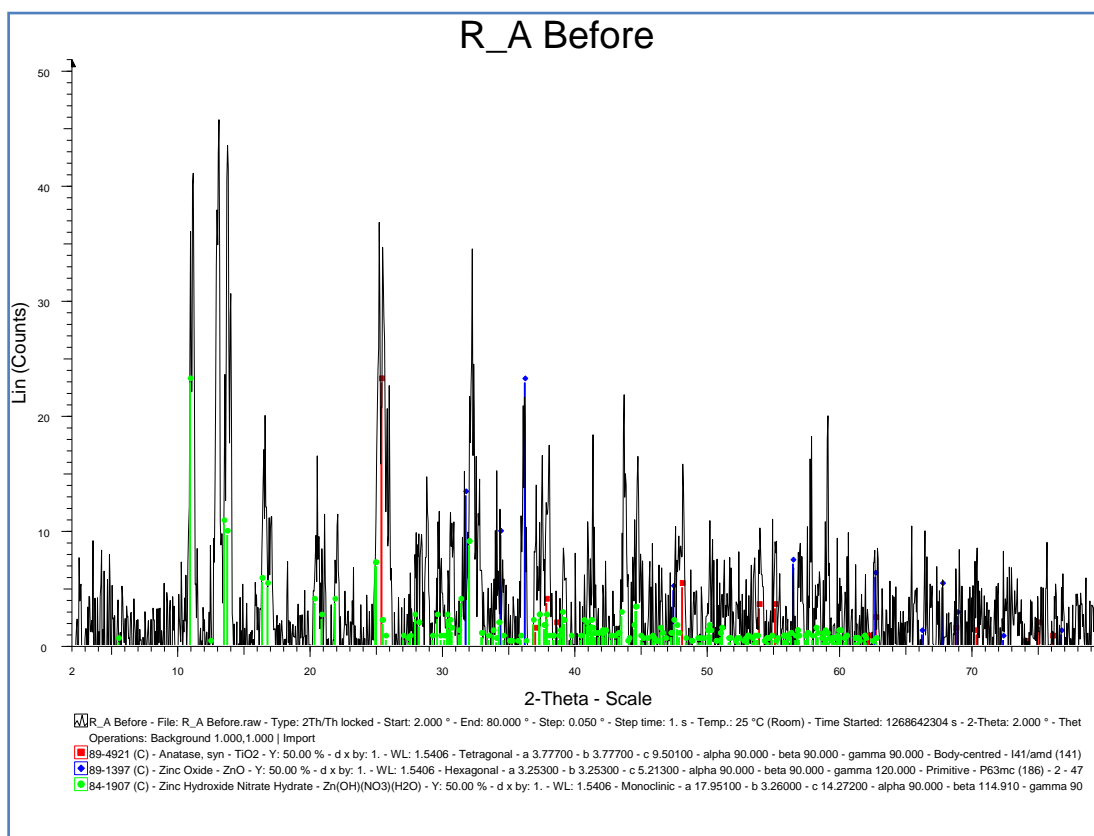
## REFERENCES

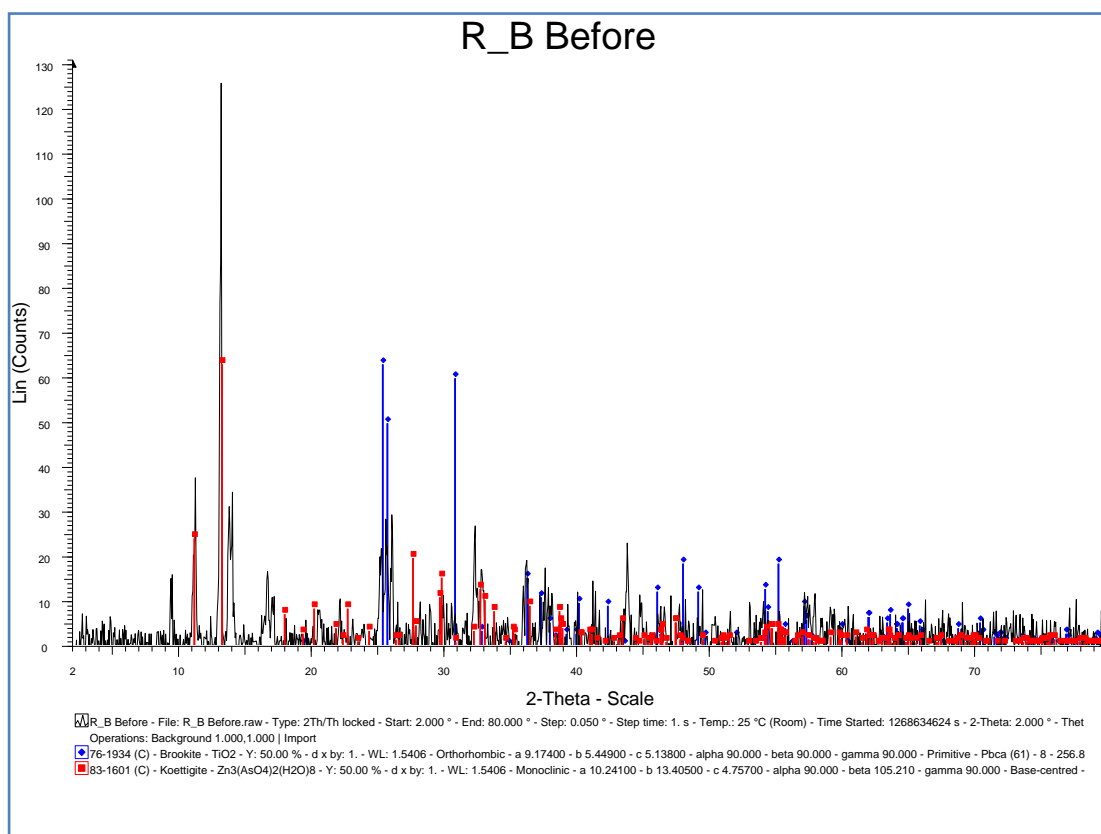
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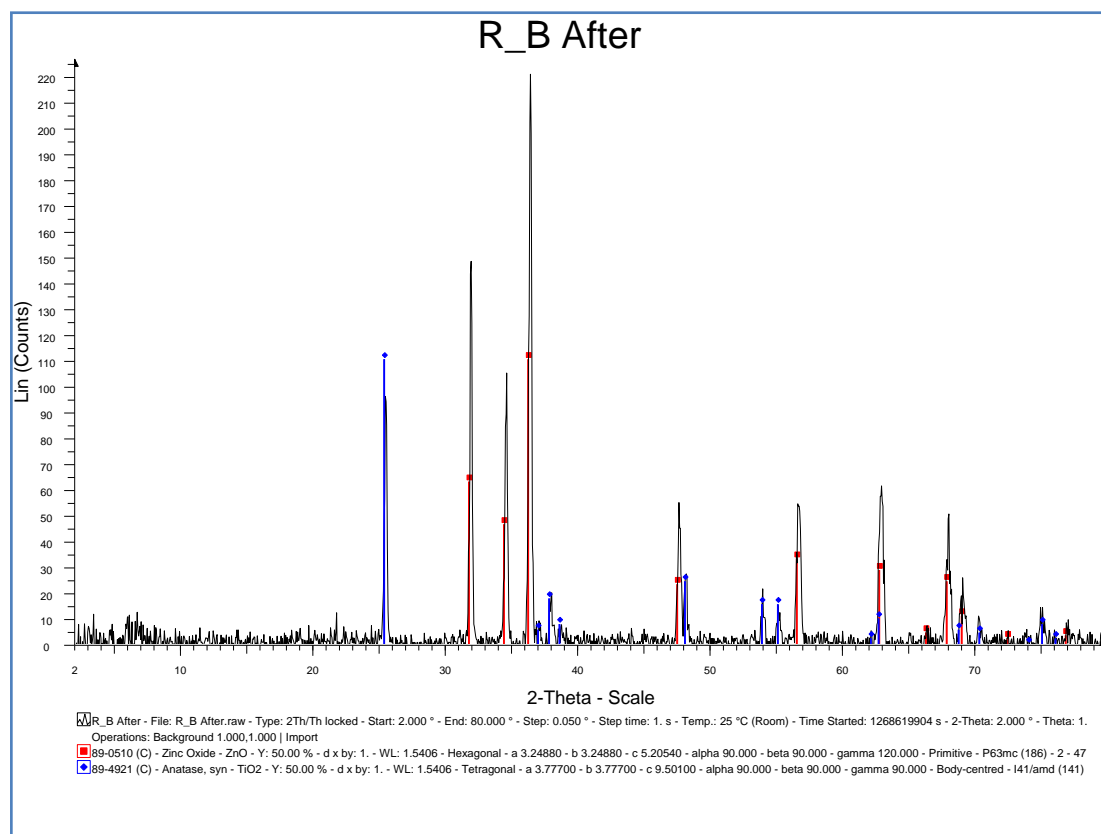
## APPENDICES

### Appendix A: XRD (before and after calcine)

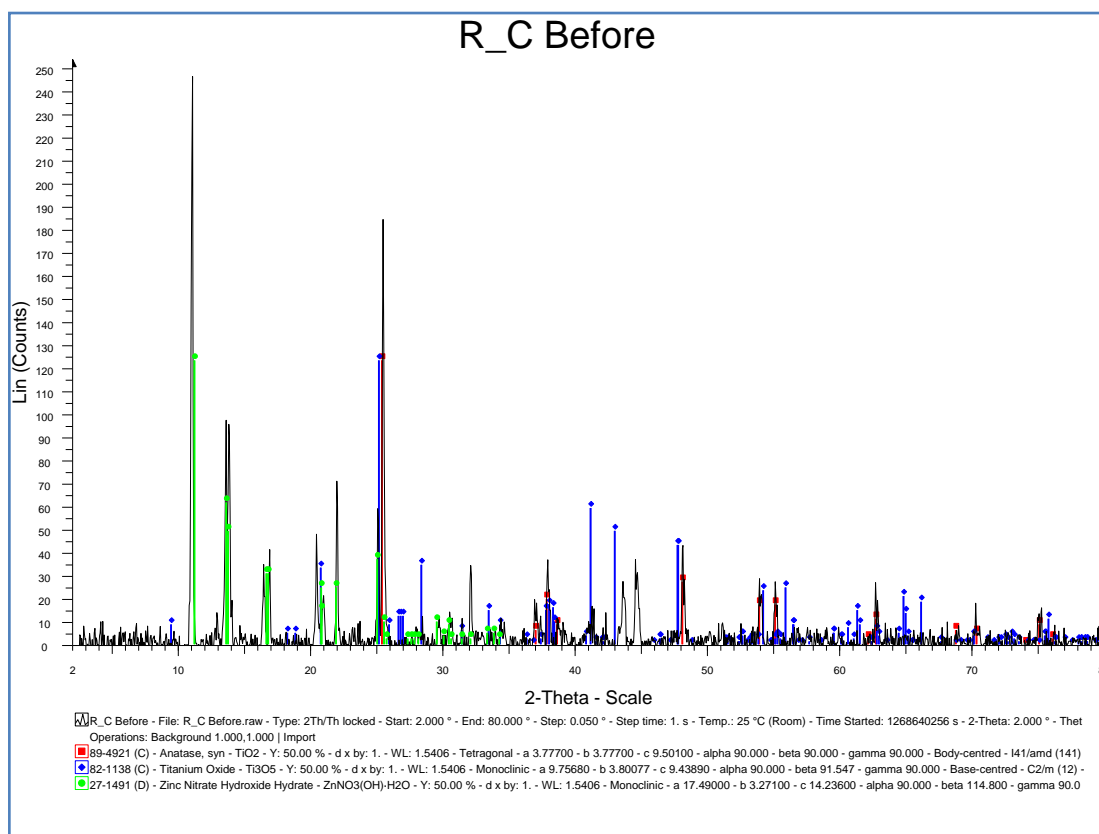




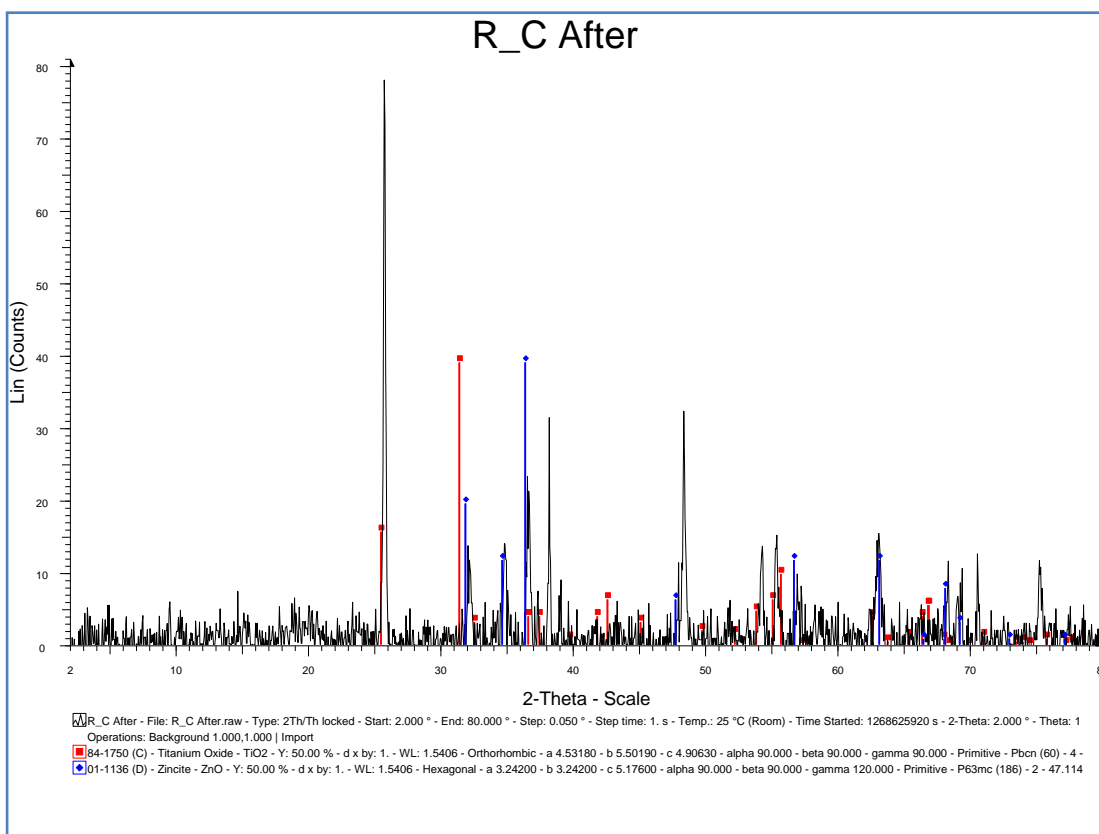
**Figure 3: Reflux 1:2 before calcine**



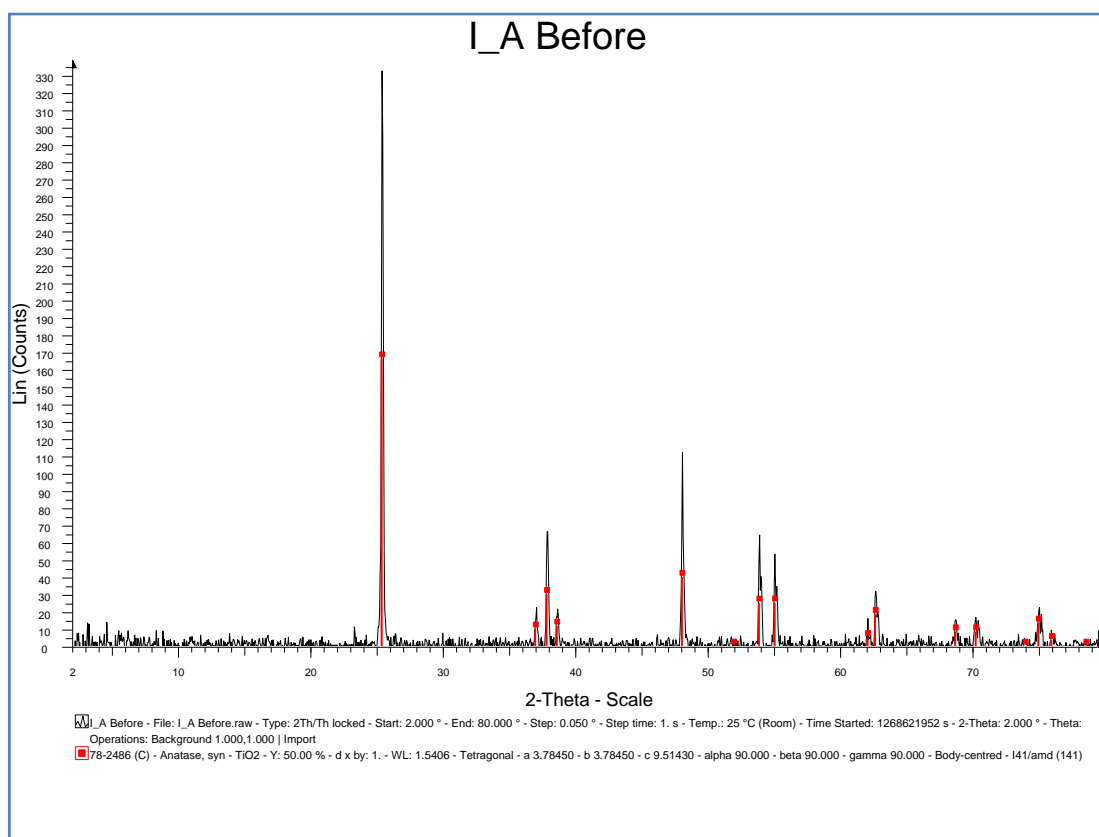
**Figure 4: Reflux 1:2 after calcine**



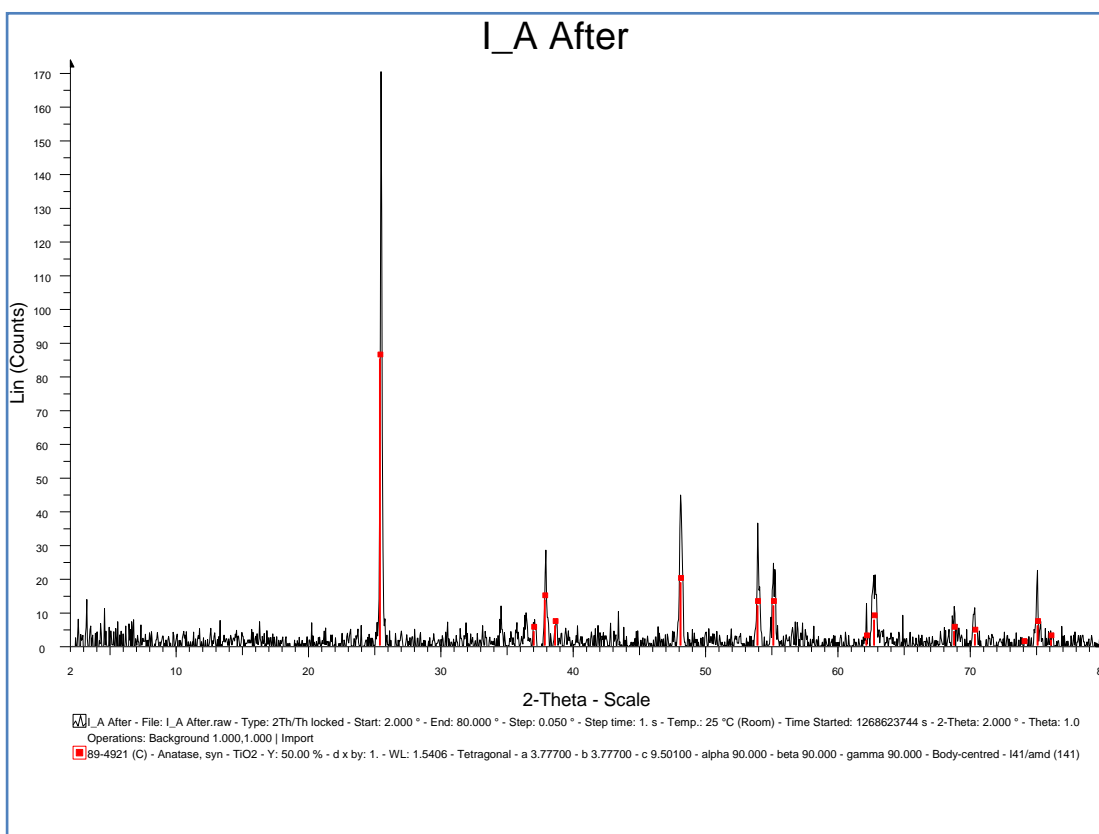
**Figure 5: Reflux 2:1 before calcine**



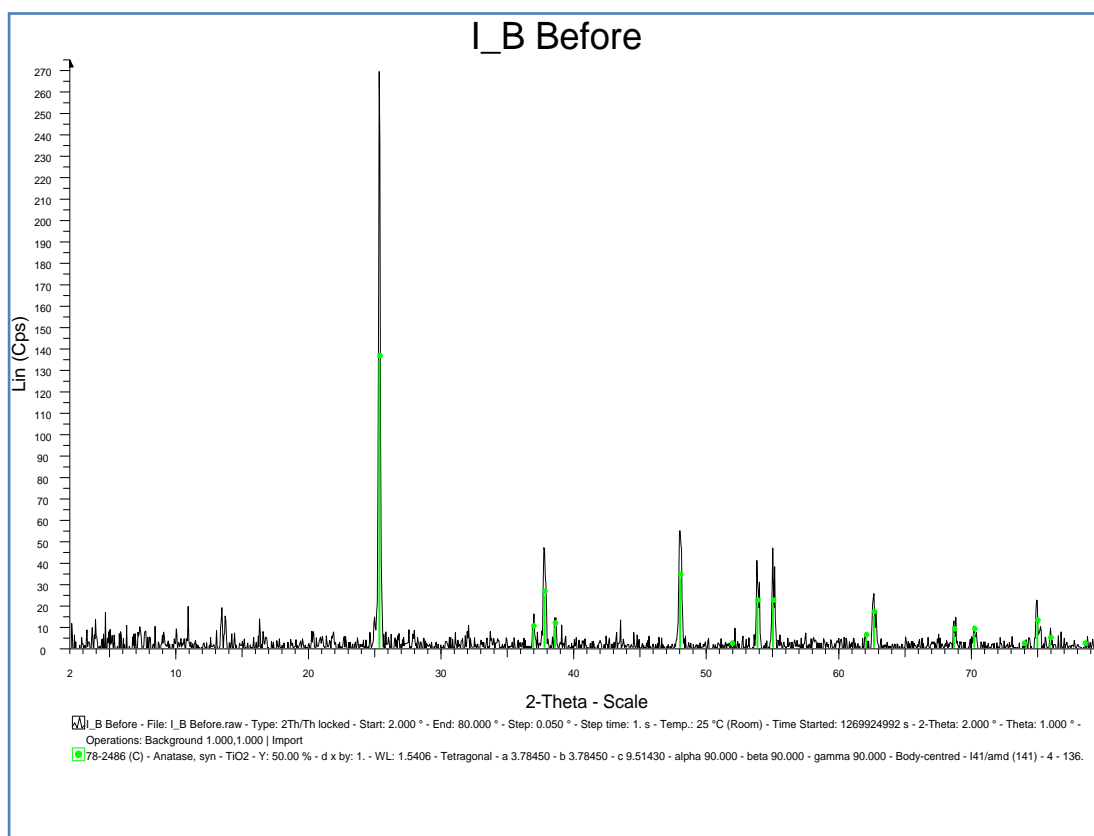
**Figure 6: Reflux 2:1 after calcine**



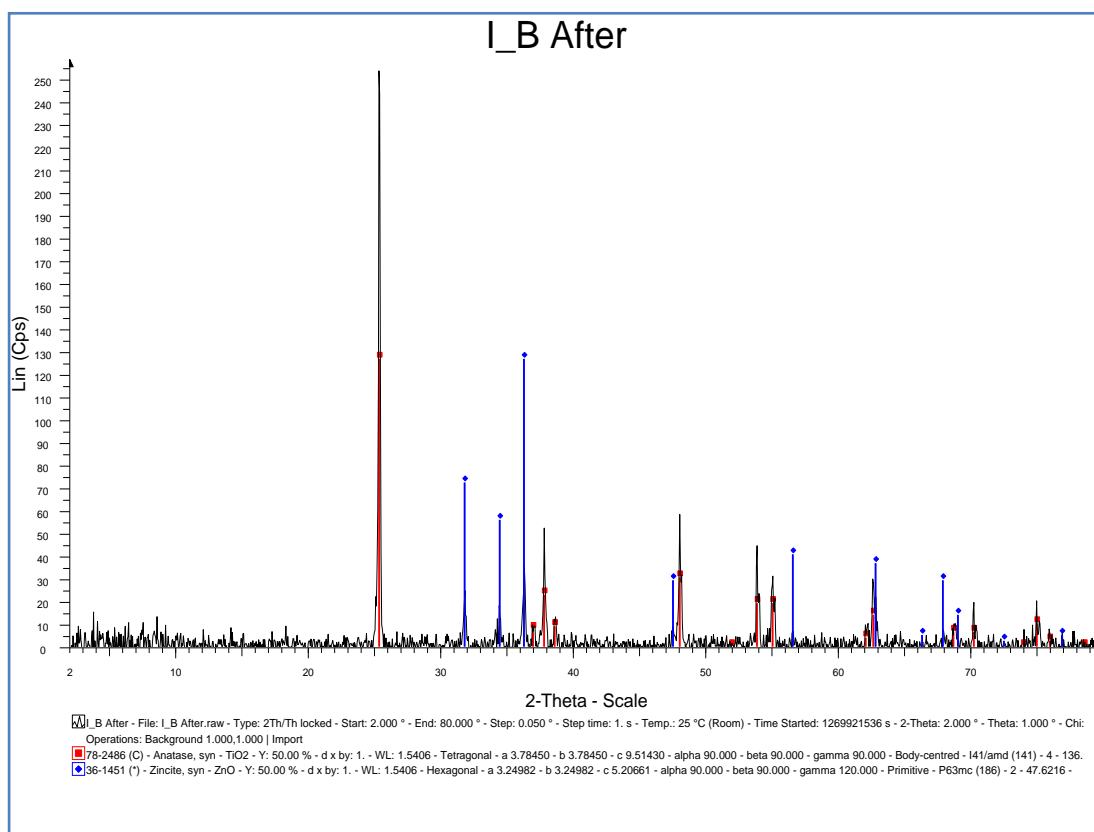
**Figure 7: Impregnation 5% before calcine**



**Figure 8: Impregnation 5% after calcine**

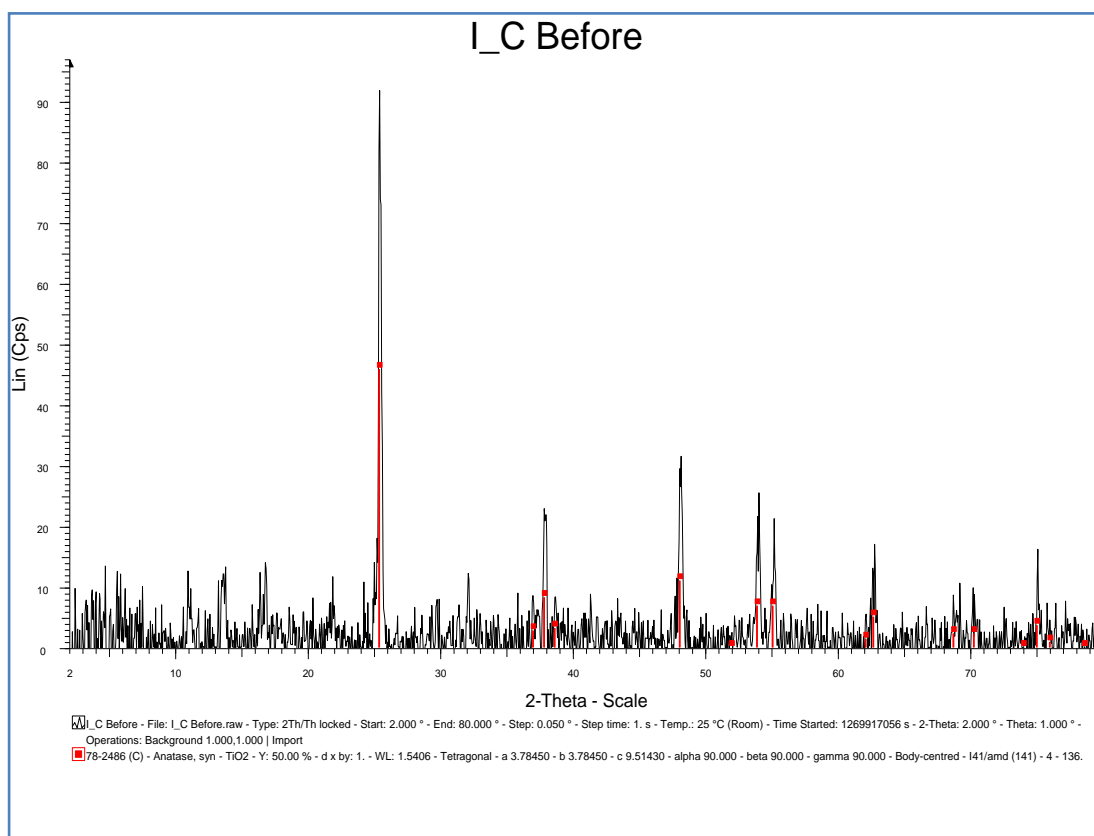


**Figure 9: Impregnation 10% before calcine**

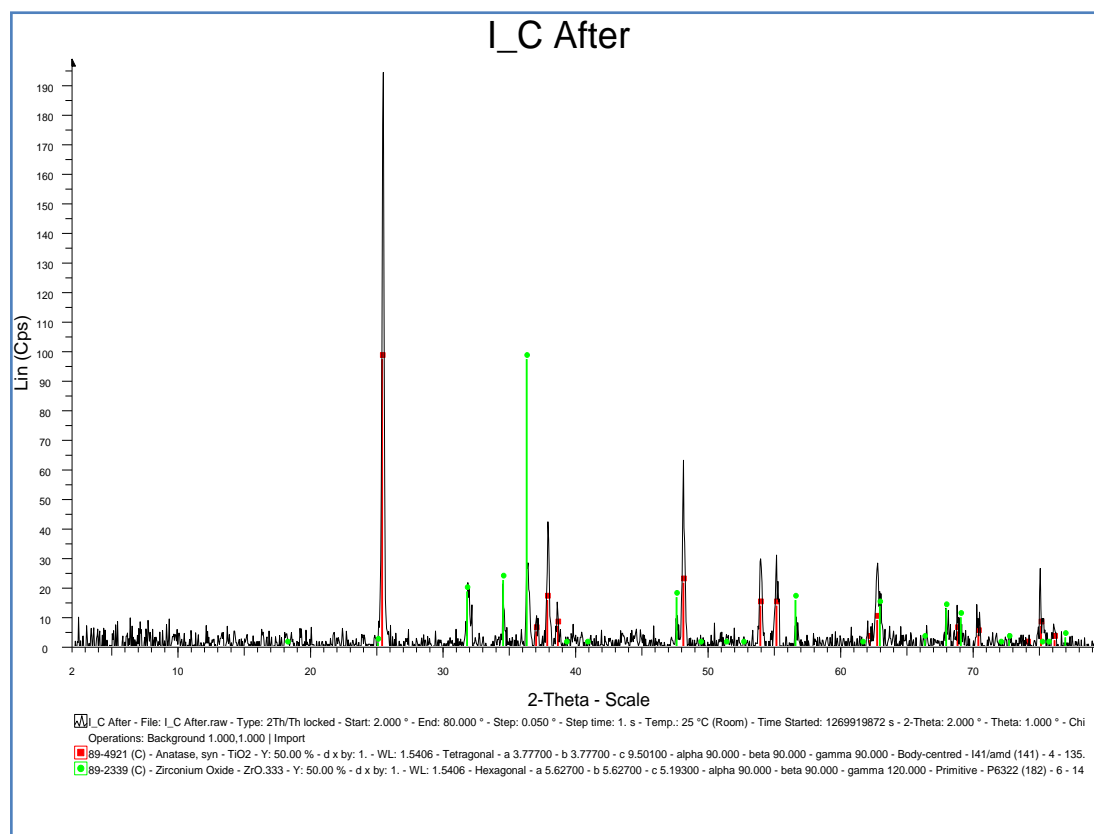


**Figure 10: Impregnation 10% after calcine**



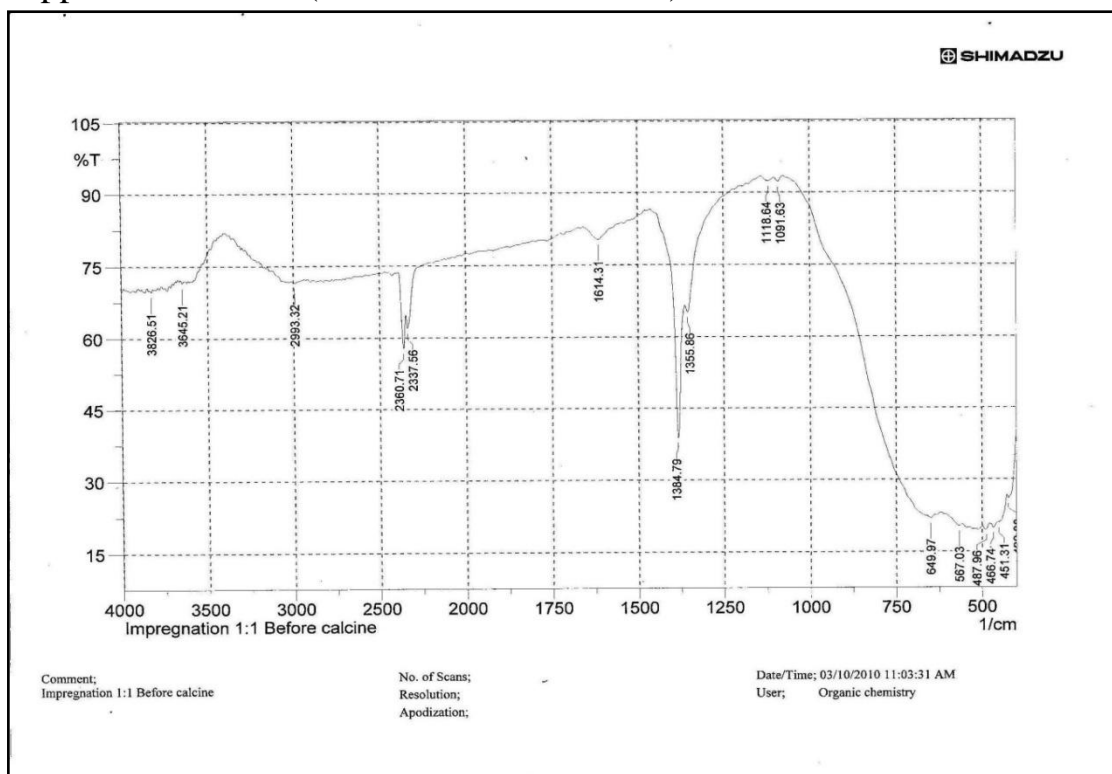


**Figure 11: Impregnation 15% before calcine**

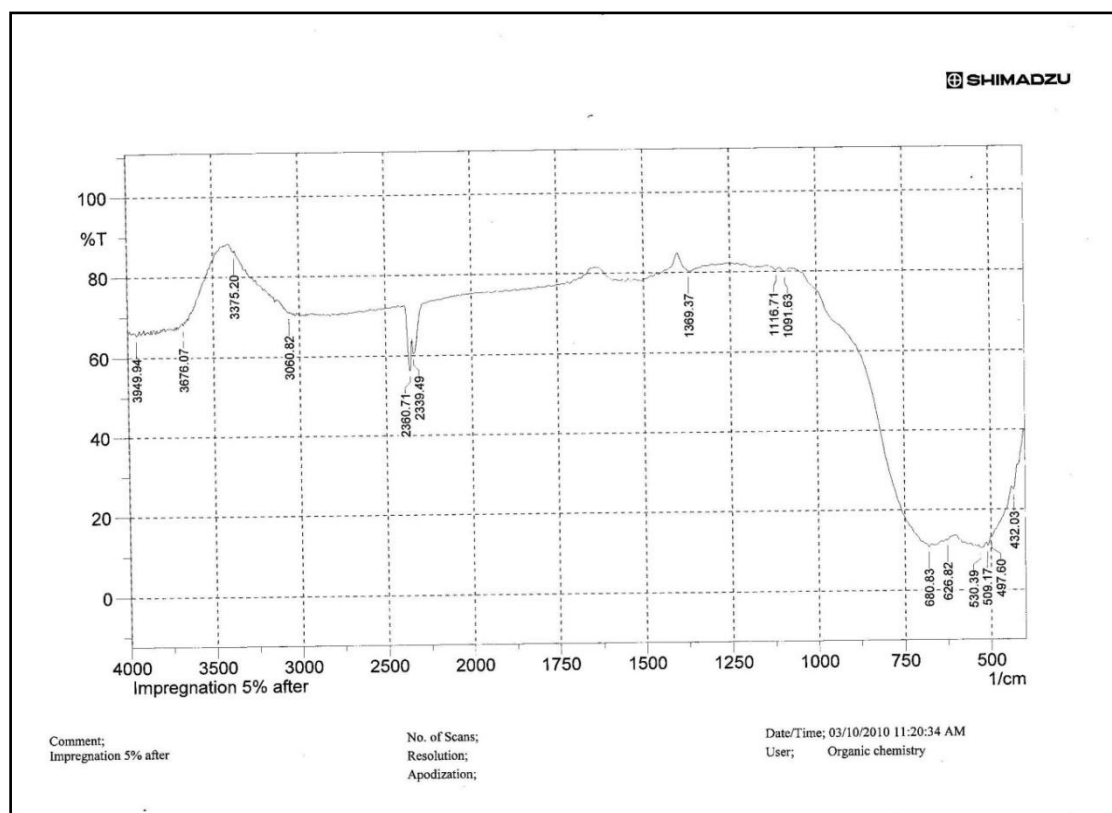


**Figure 12: Impregnation 15% after calcine**

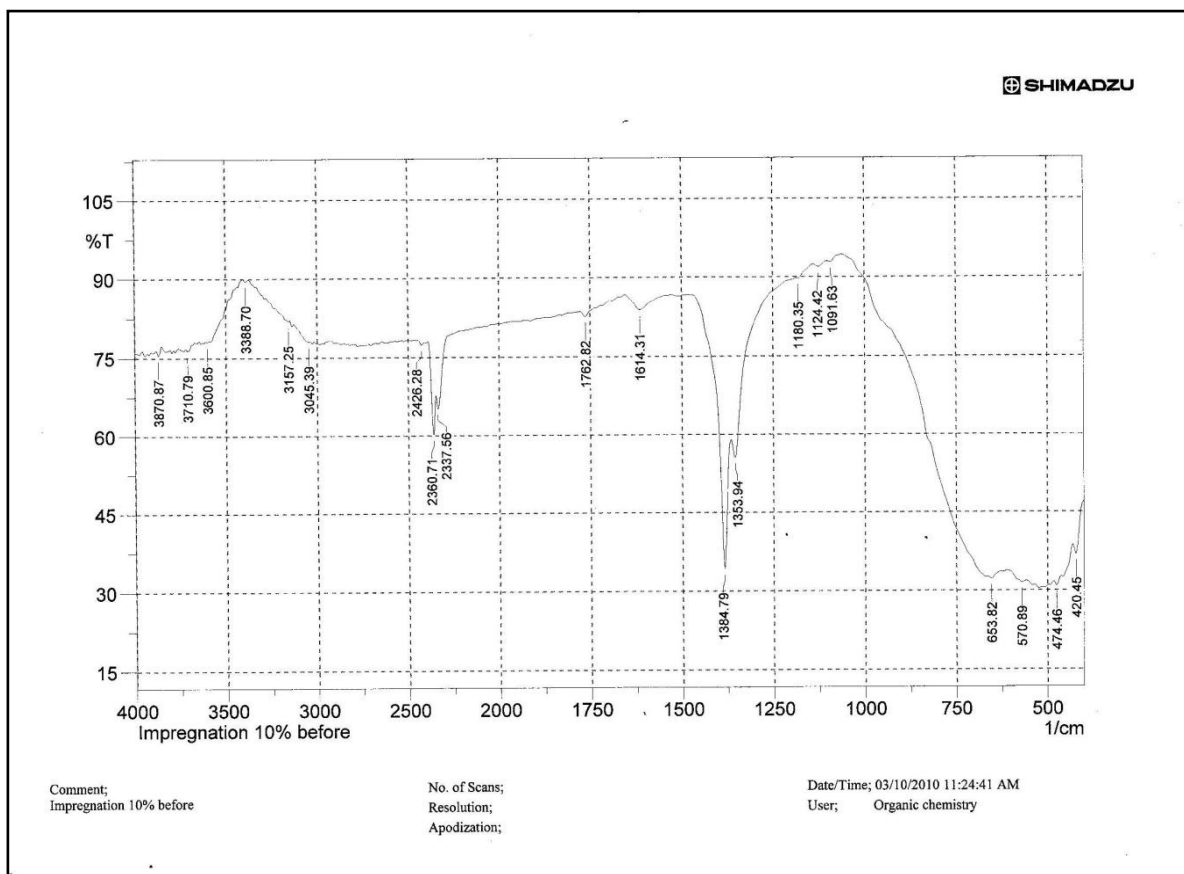
## Appendix B: FTIR (before and after calcine)



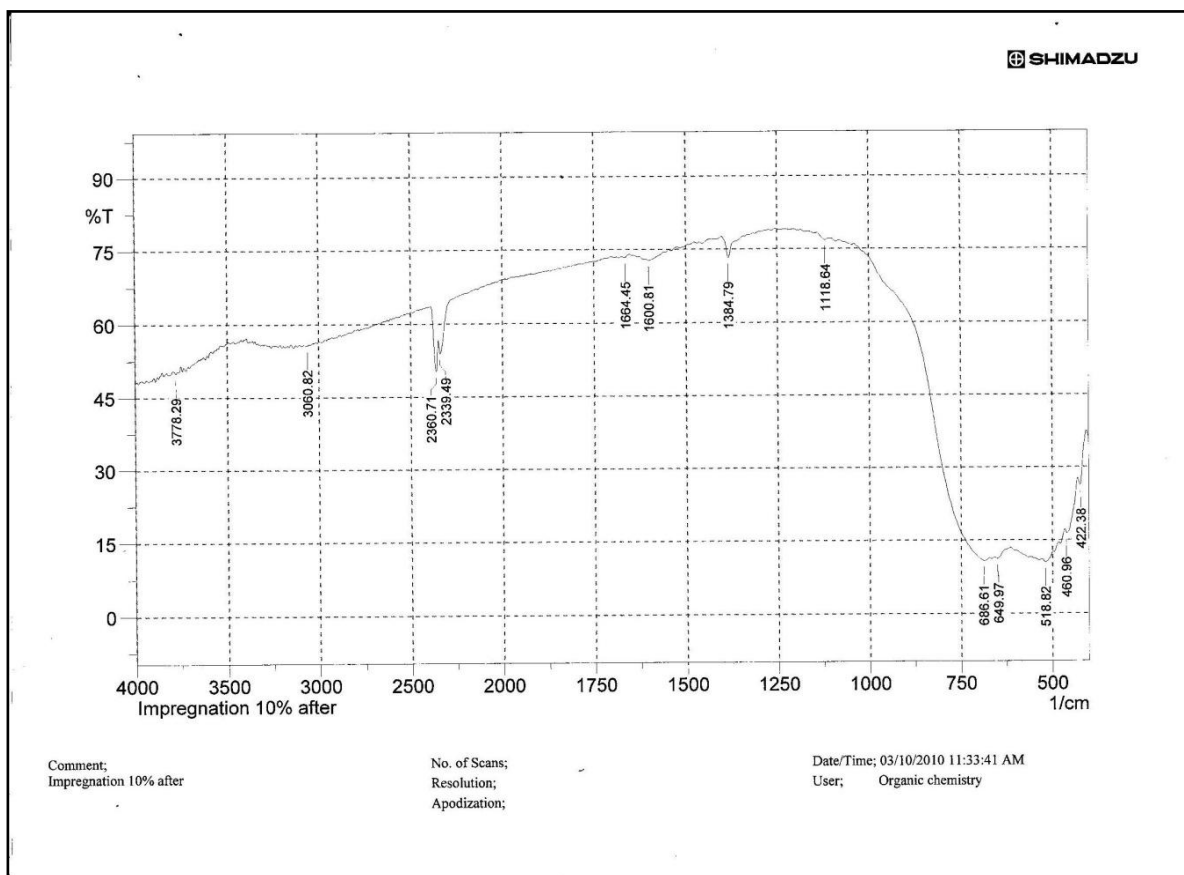
**Figure 13: Impregnation 5% before calcine**



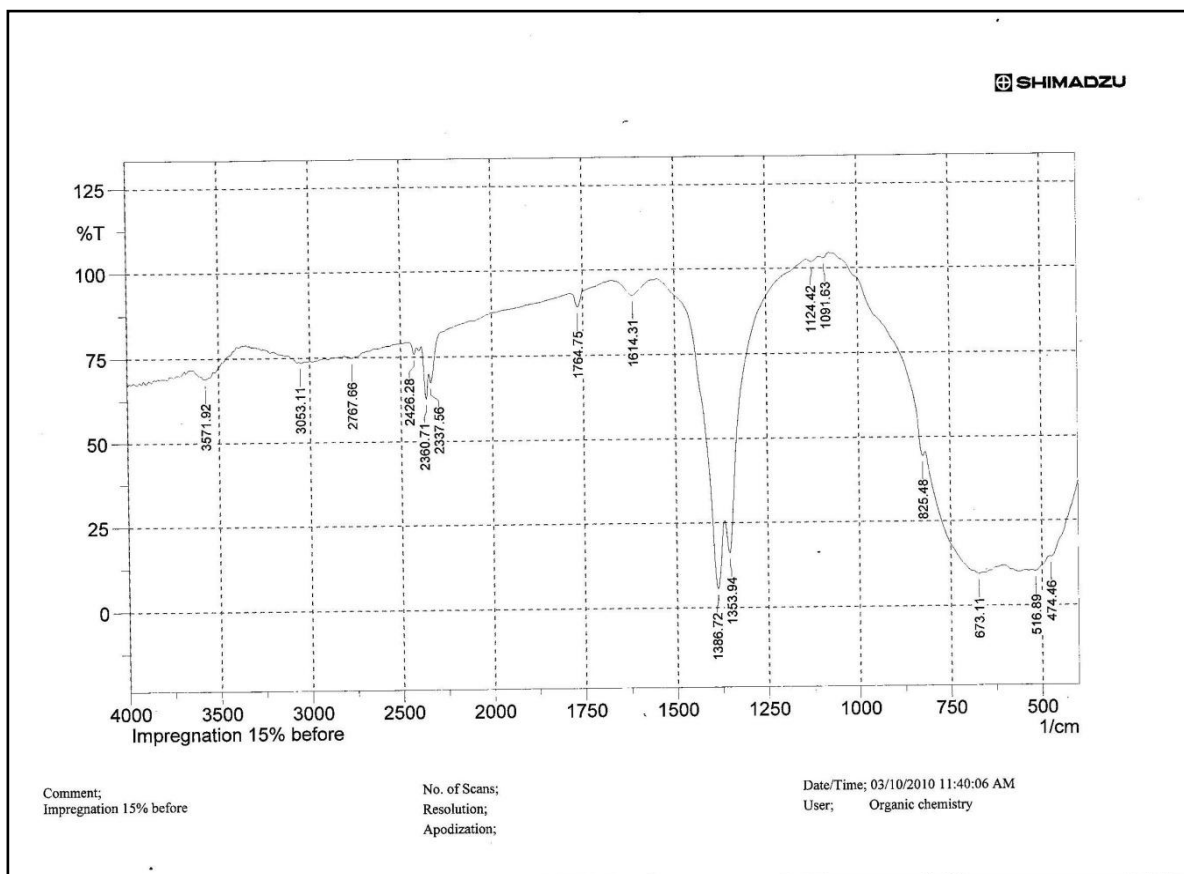
**Figure 14: Impregnation 5% after calcine**



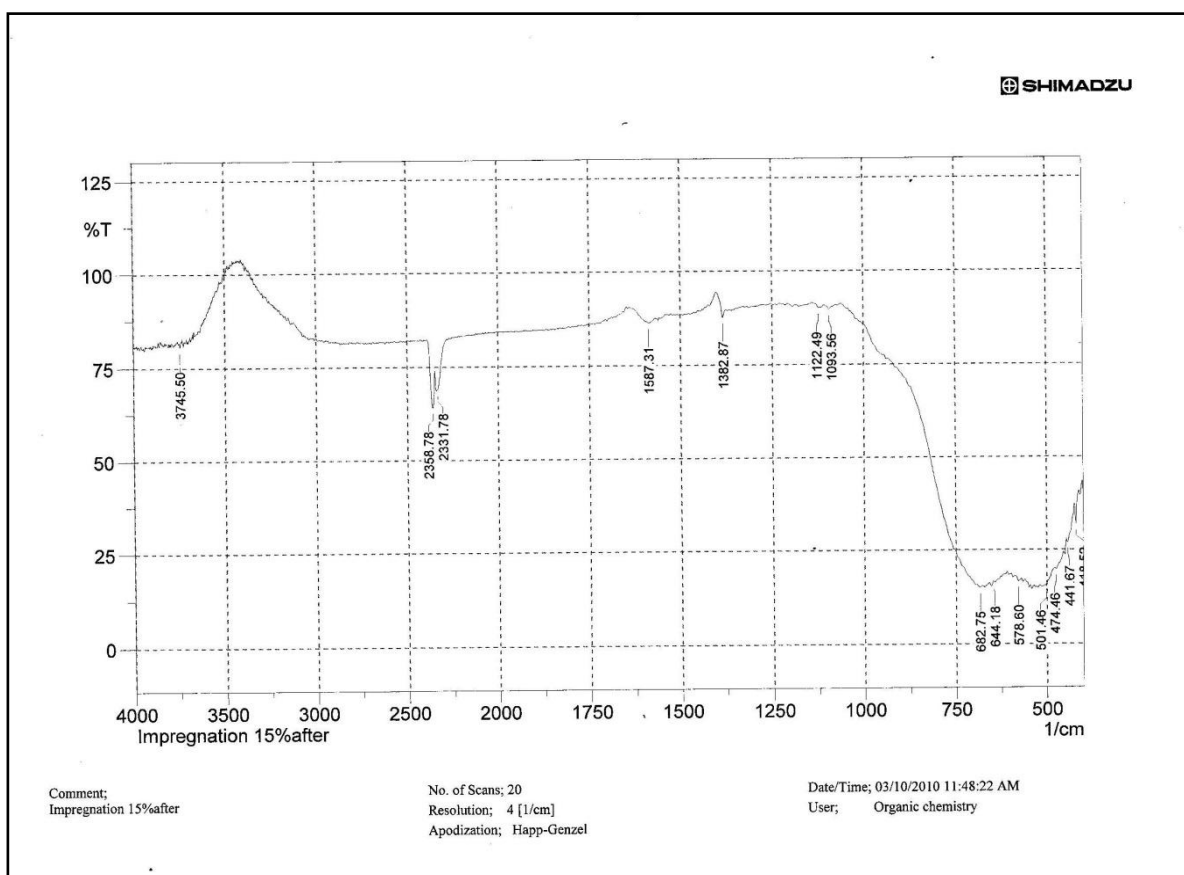
**Figure 15:** Impregnation 10% before calcine



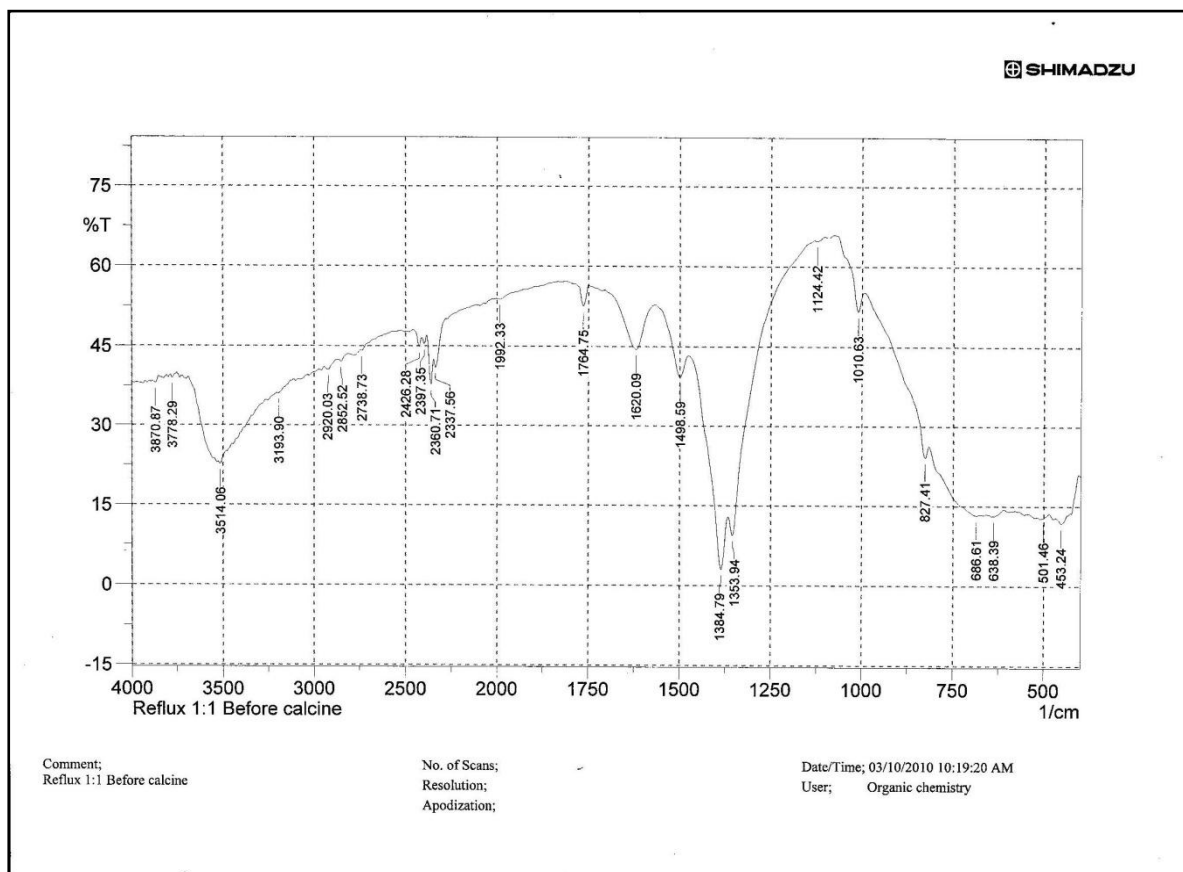
**Figure 16:** Impregnation 10% after calcine



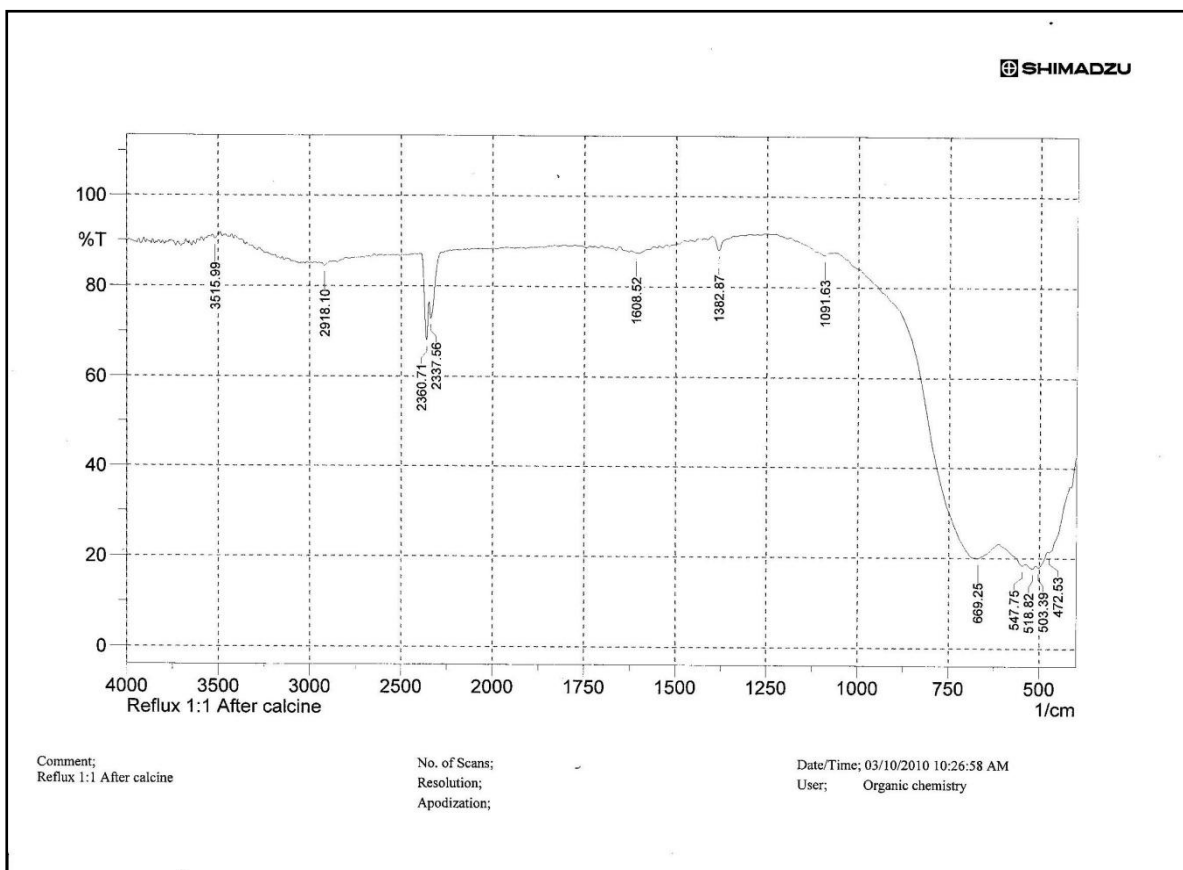
**Figure 17:** Impregnation 15% before calcine



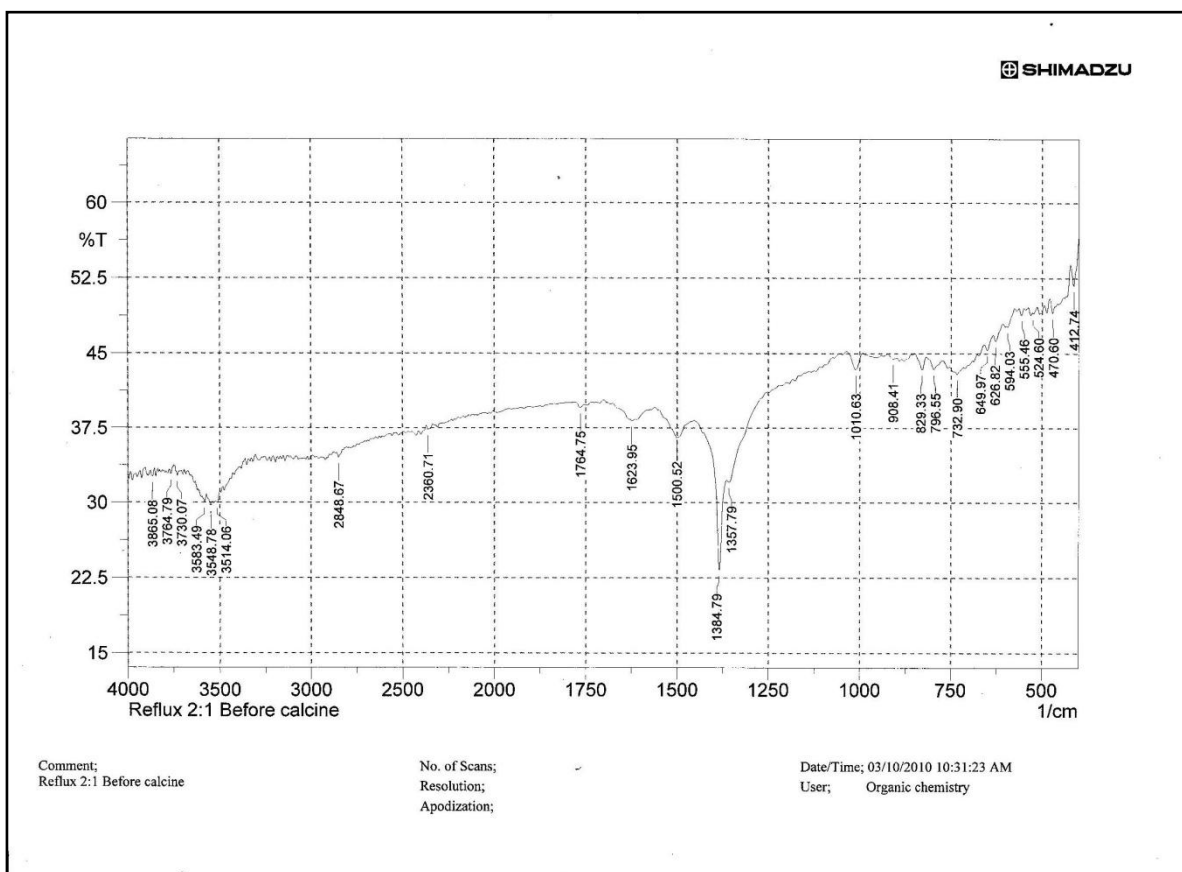
**Figure 18:** Impregnation 15% after calcine



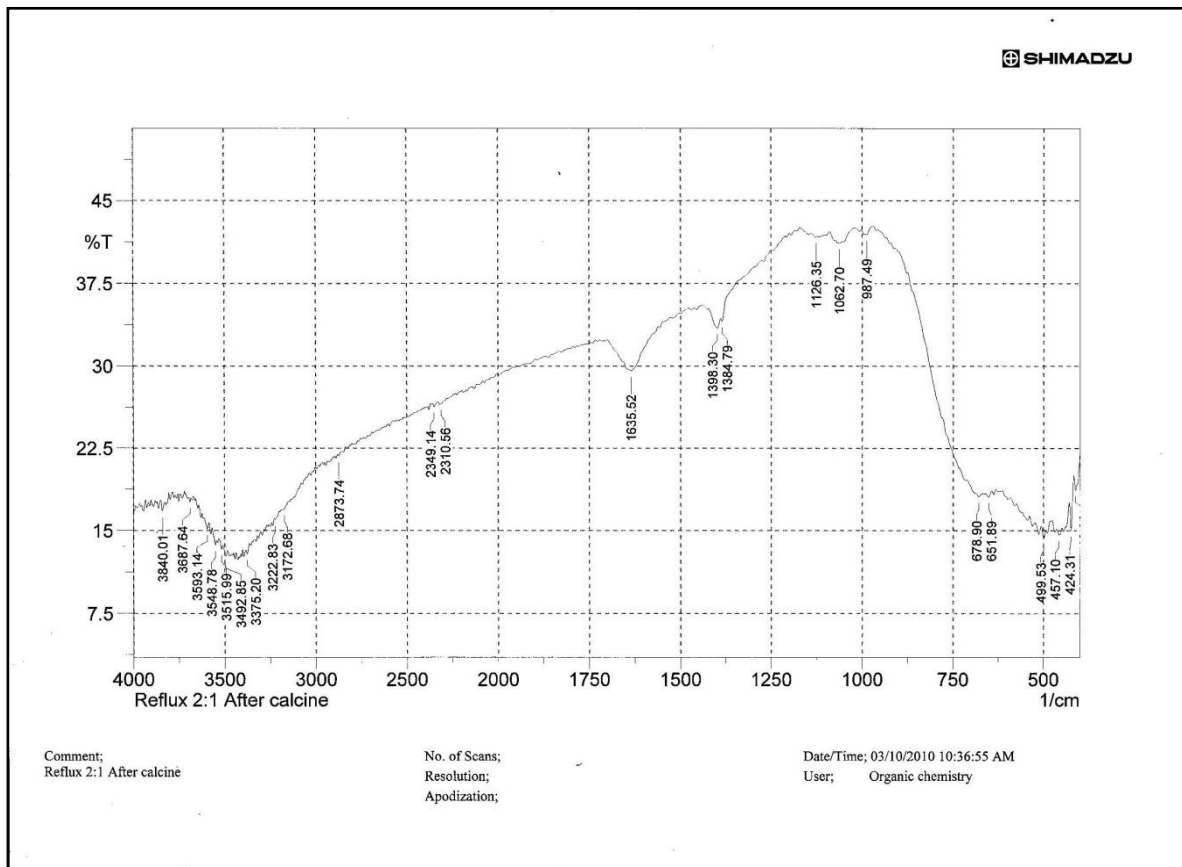
**Figure 19: Reflux 1:1 before calcine**



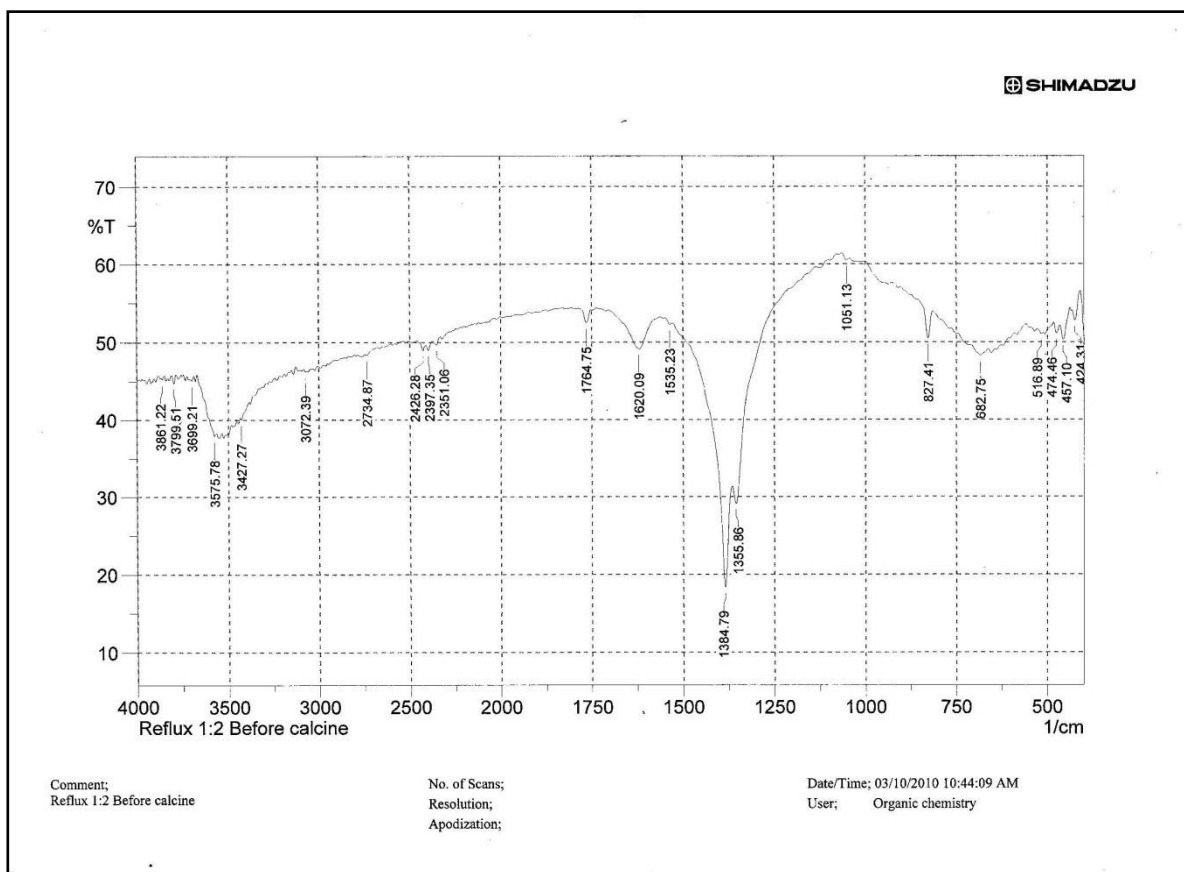
**Figure 20: Reflux 1:1 after calcine**



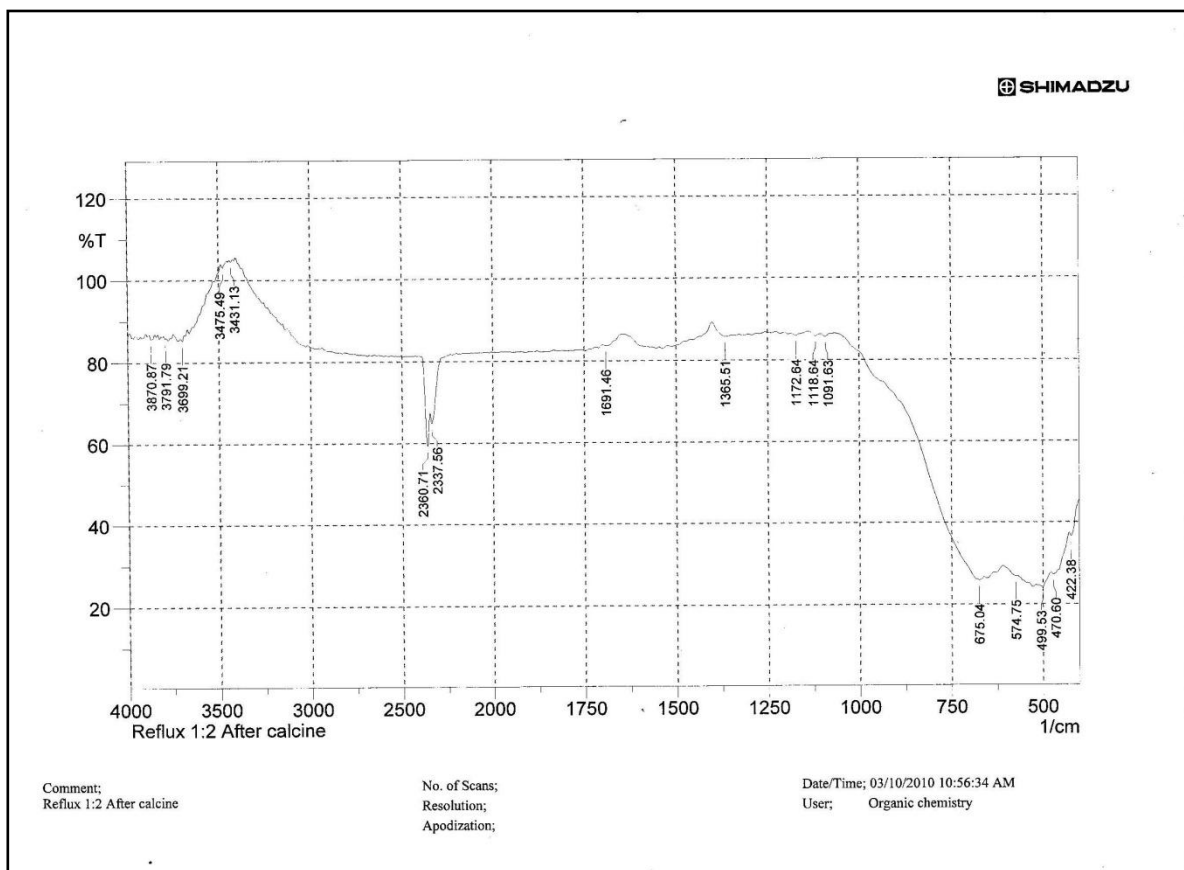
**Figure 21: Reflux 1:2 before calcine**



**Figure 22: Reflux 1:2 after calcine**



**Figure 23: Reflux 2:1 before calcine**



**Figure 24: Reflux 2:1 after calcine**

## Appendix C: UV-vis (calculation)

**Table 1: Impregnation 5%**

| 5% ZnTiO <sub>2</sub> (Impregnation) |               |             |                     |                         |        |                       |            |
|--------------------------------------|---------------|-------------|---------------------|-------------------------|--------|-----------------------|------------|
| wavelength                           | % Reflectance | Reflectance | $F(R)=(1-R)^2/(2R)$ | $v=c/\text{wavelength}$ | $E=hv$ | $\text{sqrt}(F(R)*E)$ | Absorbance |
| 800                                  | 90.038        | 0.90038     | 0.005511087         | 3.74741E+14             | 1.55   | 0.09                  | 0          |
| 795                                  | 89.984        | 0.89984     | 0.005574339         | 3.77097E+14             | 1.56   | 0.09                  | 0          |
| 790                                  | 89.922        | 0.89922     | 0.005647455         | 3.79484E+14             | 1.57   | 0.09                  | 0          |
| 785                                  | 89.955        | 0.89955     | 0.005608472         | 3.81901E+14             | 1.58   | 0.09                  | 0          |
| 780                                  | 89.909        | 0.89909     | 0.005662852         | 3.84349E+14             | 1.59   | 0.09                  | 0          |
| 775                                  | 89.888        | 0.89888     | 0.005687775         | 3.86829E+14             | 1.60   | 0.10                  | 0          |
| 770                                  | 89.859        | 0.89859     | 0.005722292         | 3.89341E+14             | 1.61   | 0.10                  | 0          |
| 765                                  | 89.868        | 0.89868     | 0.005711567         | 3.91886E+14             | 1.62   | 0.10                  | 0          |
| 760                                  | 89.9          | 0.899       | 0.005673526         | 3.94464E+14             | 1.63   | 0.10                  | 0          |
| 755                                  | 89.888        | 0.89888     | 0.005687775         | 3.97076E+14             | 1.64   | 0.10                  | 0          |
| 750                                  | 89.874        | 0.89874     | 0.005704424         | 3.99723E+14             | 1.65   | 0.10                  | 0          |
| 745                                  | 89.868        | 0.89868     | 0.005711567         | 4.02406E+14             | 1.66   | 0.10                  | 0          |
| 740                                  | 89.888        | 0.89888     | 0.005687775         | 4.05125E+14             | 1.68   | 0.10                  | 0          |
| 735                                  | 89.882        | 0.89882     | 0.005694907         | 4.07881E+14             | 1.69   | 0.10                  | 0          |
| 730                                  | 89.896        | 0.89896     | 0.005678274         | 4.10675E+14             | 1.70   | 0.10                  | 0          |
| 725                                  | 89.879        | 0.89879     | 0.005698475         | 4.13507E+14             | 1.71   | 0.10                  | 0          |
| 720                                  | 89.877        | 0.89877     | 0.005700854         | 4.16378E+14             | 1.72   | 0.10                  | 0          |
| 715                                  | 89.865        | 0.89865     | 0.005715141         | 4.1929E+14              | 1.73   | 0.10                  | 0          |
| 710                                  | 89.862        | 0.89862     | 0.005718716         | 4.22243E+14             | 1.75   | 0.10                  | 0          |
| 705                                  | 89.87         | 0.8987      | 0.005709185         | 4.25238E+14             | 1.76   | 0.10                  | 0          |
| 700                                  | 89.879        | 0.89879     | 0.005698475         | 4.28275E+14             | 1.77   | 0.10                  | 0          |
| 695                                  | 89.893        | 0.89893     | 0.005681836         | 4.31356E+14             | 1.78   | 0.10                  | 0          |
| 690                                  | 89.935        | 0.89935     | 0.00563208          | 4.34482E+14             | 1.80   | 0.10                  | 0          |
| 685                                  | 89.964        | 0.89964     | 0.005597867         | 4.37653E+14             | 1.81   | 0.10                  | 0          |
| 680                                  | 89.998        | 0.89998     | 0.005557902         | 4.40871E+14             | 1.82   | 0.10                  | 0          |
| 675                                  | 90.031        | 0.90031     | 0.005519263         | 4.44137E+14             | 1.84   | 0.10                  | 0          |
| 670                                  | 90.071        | 0.90071     | 0.005472629         | 4.47451E+14             | 1.85   | 0.10                  | 0          |
| 665                                  | 90.105        | 0.90105     | 0.005433163         | 4.50816E+14             | 1.86   | 0.10                  | 0          |
| 660                                  | 90.14         | 0.9014      | 0.0053927           | 4.54231E+14             | 1.88   | 0.10                  | 0          |
| 655                                  | 90.16         | 0.9016      | 0.005369654         | 4.57698E+14             | 1.89   | 0.10                  | 0          |
| 650                                  | 90.184        | 0.90184     | 0.00534207          | 4.61219E+14             | 1.91   | 0.10                  | 0          |
| 645                                  | 90.202        | 0.90202     | 0.005321434         | 4.64795E+14             | 1.92   | 0.10                  | 0          |
| 640                                  | 90.21         | 0.9021      | 0.005312277         | 4.68426E+14             | 1.94   | 0.10                  | 0          |
| 635                                  | 90.179        | 0.90179     | 0.005347811         | 4.72114E+14             | 1.95   | 0.10                  | 0          |
| 630                                  | 90.157        | 0.90157     | 0.005373107         | 4.75861E+14             | 1.97   | 0.10                  | 0          |
| 625                                  | 90.169        | 0.90169     | 0.005359301         | 4.79668E+14             | 1.98   | 0.10                  | 0          |
| 620                                  | 90.224        | 0.90224     | 0.005296272         | 4.83536E+14             | 2.00   | 0.10                  | 0          |
| 615                                  | 90.222        | 0.90222     | 0.005298557         | 4.87467E+14             | 2.02   | 0.10                  | 0          |
| 610                                  | 90.199        | 0.90199     | 0.005324871         | 4.91463E+14             | 2.03   | 0.10                  | 0          |
| 605                                  | 90.163        | 0.90163     | 0.005366202         | 4.95525E+14             | 2.05   | 0.10                  | 0          |
| 600                                  | 90.143        | 0.90143     | 0.00538924          | 4.99654E+14             | 2.07   | 0.11                  | 0          |
| 595                                  | 90.115        | 0.90115     | 0.005421585         | 5.03853E+14             | 2.08   | 0.11                  | 0          |
| 590                                  | 90.083        | 0.90083     | 0.005458682         | 5.08123E+14             | 2.10   | 0.11                  | 0          |
| 585                                  | 90.038        | 0.90038     | 0.005511087         | 5.12466E+14             | 2.12   | 0.11                  | 0          |
| 580                                  | 89.999        | 0.89999     | 0.005556728         | 5.16884E+14             | 2.14   | 0.11                  | 0          |
| 575                                  | 89.951        | 0.89951     | 0.005613189         | 5.21378E+14             | 2.16   | 0.11                  | 0          |



|     |        |         |             |             |      |      |       |
|-----|--------|---------|-------------|-------------|------|------|-------|
| 570 | 89.899 | 0.89899 | 0.005674713 | 5.25952E+14 | 2.18 | 0.11 | 0     |
| 565 | 89.847 | 0.89847 | 0.005736608 | 5.30606E+14 | 2.19 | 0.11 | 0     |
| 560 | 89.789 | 0.89789 | 0.005806085 | 5.35344E+14 | 2.21 | 0.11 | 0     |
| 555 | 89.734 | 0.89734 | 0.005872398 | 5.40167E+14 | 2.23 | 0.11 | 0     |
| 550 | 89.664 | 0.89664 | 0.005957402 | 5.45077E+14 | 2.25 | 0.12 | 0     |
| 545 | 89.609 | 0.89609 | 0.006024667 | 5.50078E+14 | 2.27 | 0.12 | 0     |
| 540 | 89.542 | 0.89542 | 0.006107177 | 5.55171E+14 | 2.30 | 0.12 | 0     |
| 535 | 89.508 | 0.89508 | 0.006149286 | 5.6036E+14  | 2.32 | 0.12 | 0     |
| 530 | 89.439 | 0.89439 | 0.00623524  | 5.65646E+14 | 2.34 | 0.12 | 0     |
| 525 | 89.38  | 0.8938  | 0.006309264 | 5.71033E+14 | 2.36 | 0.12 | 0     |
| 520 | 89.322 | 0.89322 | 0.006382508 | 5.76524E+14 | 2.38 | 0.12 | 0     |
| 515 | 89.25  | 0.8925  | 0.00647409  | 5.82121E+14 | 2.41 | 0.12 | 0     |
| 510 | 89.165 | 0.89165 | 0.006583145 | 5.87828E+14 | 2.43 | 0.13 | 0     |
| 505 | 89.058 | 0.89058 | 0.006721876 | 5.93648E+14 | 2.46 | 0.13 | 0     |
| 500 | 88.977 | 0.88977 | 0.006827974 | 5.99585E+14 | 2.48 | 0.13 | 0     |
| 495 | 88.889 | 0.88889 | 0.006944297 | 6.05641E+14 | 2.50 | 0.13 | 0     |
| 490 | 88.785 | 0.88785 | 0.007083191 | 6.11821E+14 | 2.53 | 0.13 | 0     |
| 485 | 88.664 | 0.88664 | 0.007246735 | 6.18129E+14 | 2.56 | 0.14 | 0     |
| 480 | 88.551 | 0.88551 | 0.007401362 | 6.24568E+14 | 2.58 | 0.14 | 0     |
| 475 | 88.435 | 0.88435 | 0.007562007 | 6.31142E+14 | 2.61 | 0.14 | 0     |
| 470 | 88.295 | 0.88295 | 0.007758482 | 6.37856E+14 | 2.64 | 0.14 | 0     |
| 465 | 88.152 | 0.88152 | 0.007962105 | 6.44715E+14 | 2.67 | 0.15 | 0     |
| 460 | 88.002 | 0.88002 | 0.008178905 | 6.51723E+14 | 2.70 | 0.15 | 0     |
| 455 | 87.851 | 0.87851 | 0.008400485 | 6.58885E+14 | 2.72 | 0.15 | 0     |
| 450 | 87.679 | 0.87679 | 0.008656978 | 6.66205E+14 | 2.76 | 0.15 | 0     |
| 445 | 87.485 | 0.87485 | 0.008951547 | 6.73691E+14 | 2.79 | 0.16 | 0     |
| 440 | 87.268 | 0.87268 | 0.009287701 | 6.81346E+14 | 2.82 | 0.16 | 0     |
| 435 | 86.992 | 0.86992 | 0.009725496 | 6.89178E+14 | 2.85 | 0.17 | 0     |
| 430 | 86.694 | 0.86694 | 0.010211182 | 6.97192E+14 | 2.88 | 0.17 | 0     |
| 425 | 86.34  | 0.8634  | 0.010805861 | 7.05394E+14 | 2.92 | 0.18 | 0     |
| 420 | 85.858 | 0.85858 | 0.011646915 | 7.13792E+14 | 2.95 | 0.19 | 0     |
| 415 | 85.191 | 0.85191 | 0.012871458 | 7.22391E+14 | 2.99 | 0.20 | 0     |
| 410 | 84.248 | 0.84248 | 0.014725899 | 7.31201E+14 | 3.02 | 0.21 | 0     |
| 405 | 82.846 | 0.82846 | 0.01775944  | 7.40228E+14 | 3.06 | 0.23 | 0     |
| 400 | 80.637 | 0.80637 | 0.02324775  | 7.49481E+14 | 3.10 | 0.27 | 0     |
| 395 | 77.121 | 0.77121 | 0.033936842 | 7.58968E+14 | 3.14 | 0.33 | 0     |
| 390 | 71.663 | 0.71663 | 0.056025115 | 7.68699E+14 | 3.18 | 0.42 | 0.001 |
| 385 | 63.817 | 0.63817 | 0.102575293 | 7.78682E+14 | 3.22 | 0.57 | 0.001 |
| 380 | 53.886 | 0.53886 | 0.197314794 | 7.88928E+14 | 3.26 | 0.80 | 0.002 |
| 375 | 42.836 | 0.42836 | 0.381422506 | 7.99447E+14 | 3.31 | 1.12 | 0.004 |
| 370 | 32.079 | 0.32079 | 0.719047078 | 8.1025E+14  | 3.35 | 1.55 | 0.007 |
| 365 | 22.824 | 0.22824 | 1.304796481 | 8.21349E+14 | 3.40 | 2.11 | 0.013 |
| 360 | 15.851 | 0.15851 | 2.233630118 | 8.32757E+14 | 3.44 | 2.77 | 0.022 |
| 355 | 11.272 | 0.11272 | 3.49213005  | 8.44486E+14 | 3.49 | 3.49 | 0.035 |
| 350 | 8.582  | 0.08582 | 4.869057751 | 8.5655E+14  | 3.54 | 4.15 | 0.049 |
| 345 | 7.074  | 0.07074 | 6.103506839 | 8.68964E+14 | 3.59 | 4.68 | 0.061 |
| 340 | 6.215  | 0.06215 | 7.076127293 | 8.81743E+14 | 3.65 | 5.08 | 0.071 |
| 335 | 5.772  | 0.05772 | 7.691368663 | 8.94903E+14 | 3.70 | 5.34 | 0.077 |
| 330 | 5.598  | 0.05598 | 7.959751343 | 9.08462E+14 | 3.76 | 5.47 | 0.08  |
| 325 | 5.542  | 0.05542 | 8.049723713 | 9.22438E+14 | 3.81 | 5.54 | 0.08  |
| 320 | 5.537  | 0.05537 | 8.057845737 | 9.36851E+14 | 3.87 | 5.59 | 0.081 |
| 315 | 5.553  | 0.05553 | 8.031906905 | 9.51722E+14 | 3.94 | 5.62 | 0.08  |
| 310 | 5.573  | 0.05573 | 7.999693459 | 9.67072E+14 | 4.00 | 5.66 | 0.08  |
| 305 | 5.629  | 0.05629 | 7.910717393 | 9.82926E+14 | 4.07 | 5.67 | 0.079 |
| 300 | 5.73   | 0.0573  | 7.75465349  | 9.99308E+14 | 4.13 | 5.66 | 0.078 |
| 295 | 5.861  | 0.05861 | 7.560272412 | 1.01625E+15 | 4.20 | 5.64 | 0.076 |

|     |       |         |             |             |      |      |       |
|-----|-------|---------|-------------|-------------|------|------|-------|
| 290 | 5.984 | 0.05984 | 7.385534973 | 1.03377E+15 | 4.28 | 5.62 | 0.074 |
| 285 | 6.071 | 0.06071 | 7.266230474 | 1.0519E+15  | 4.35 | 5.62 | 0.073 |
| 280 | 6.131 | 0.06131 | 7.185931464 | 1.07069E+15 | 4.43 | 5.64 | 0.072 |
| 275 | 6.166 | 0.06166 | 7.139814755 | 1.09015E+15 | 4.51 | 5.67 | 0.071 |
| 270 | 6.195 | 0.06195 | 7.10200002  | 1.11034E+15 | 4.59 | 5.71 | 0.071 |
| 265 | 6.213 | 0.06213 | 7.078707041 | 1.13129E+15 | 4.68 | 5.75 | 0.071 |
| 260 | 6.198 | 0.06198 | 7.098108425 | 1.15305E+15 | 4.77 | 5.82 | 0.071 |
| 255 | 6.131 | 0.06131 | 7.185931464 | 1.17566E+15 | 4.86 | 5.91 | 0.072 |
| 250 | 5.997 | 0.05997 | 7.367487084 | 1.19917E+15 | 4.96 | 6.04 | 0.074 |
| 245 | 5.823 | 0.05823 | 7.615754189 | 1.22364E+15 | 5.06 | 6.21 | 0.076 |
| 240 | 5.647 | 0.05647 | 7.882493899 | 1.24914E+15 | 5.17 | 6.38 | 0.079 |
| 235 | 5.493 | 0.05493 | 8.129959083 | 1.27571E+15 | 5.28 | 6.55 | 0.081 |
| 230 | 5.383 | 0.05383 | 8.315415836 | 1.30345E+15 | 5.39 | 6.70 | 0.083 |
| 225 | 5.304 | 0.05304 | 8.453367662 | 1.33241E+15 | 5.51 | 6.83 | 0.085 |
| 220 | 5.273 | 0.05273 | 8.508633159 | 1.36269E+15 | 5.64 | 6.92 | 0.085 |
| 215 | 5.267 | 0.05267 | 8.519405059 | 1.39438E+15 | 5.77 | 7.01 | 0.085 |
| 210 | 5.309 | 0.05309 | 8.444514486 | 1.42758E+15 | 5.90 | 7.06 | 0.084 |
| 205 | 5.38  | 0.0538  | 8.320580297 | 1.4624E+15  | 6.05 | 7.09 | 0.083 |
| 200 | 5.469 | 0.05469 | 8.169784203 | 1.49896E+15 | 6.20 | 7.12 | 0.082 |

**Table 2: Impregnation 10%**

| 10% ZnTiO <sub>2</sub> (Impregnation) |               |             |                     |                         |        |                       |            |
|---------------------------------------|---------------|-------------|---------------------|-------------------------|--------|-----------------------|------------|
| wavelength                            | % Reflectance | Reflectance | $F(R)=(1-R)^2/(2R)$ | $v=c/\text{wavelength}$ | $E=hv$ | $\text{sqrt}(F(R)*E)$ | Absorbance |
| 800                                   | 90.216        | 0.90216     | 0.005305415         | 3.74741E+14             | 1.55   | 0.09                  | 0          |
| 795                                   | 90.256        | 0.90256     | 0.005259791         | 3.77097E+14             | 1.56   | 0.09                  | 0          |
| 790                                   | 90.265        | 0.90265     | 0.005249555         | 3.79484E+14             | 1.57   | 0.09                  | 0          |
| 785                                   | 90.279        | 0.90279     | 0.005233656         | 3.81901E+14             | 1.58   | 0.09                  | 0          |
| 780                                   | 90.259        | 0.90259     | 0.005256378         | 3.84349E+14             | 1.59   | 0.09                  | 0          |
| 775                                   | 90.221        | 0.90221     | 0.0052997           | 3.86829E+14             | 1.60   | 0.09                  | 0          |
| 770                                   | 90.204        | 0.90204     | 0.005319144         | 3.89341E+14             | 1.61   | 0.09                  | 0          |
| 765                                   | 90.179        | 0.90179     | 0.005347811         | 3.91886E+14             | 1.62   | 0.09                  | 0          |
| 760                                   | 90.196        | 0.90196     | 0.005328308         | 3.94464E+14             | 1.63   | 0.09                  | 0          |
| 755                                   | 90.202        | 0.90202     | 0.005321434         | 3.97076E+14             | 1.64   | 0.09                  | 0          |
| 750                                   | 90.175        | 0.90175     | 0.005352405         | 3.99723E+14             | 1.65   | 0.09                  | 0          |
| 745                                   | 90.164        | 0.90164     | 0.005365051         | 4.02406E+14             | 1.66   | 0.09                  | 0          |
| 740                                   | 90.175        | 0.90175     | 0.005352405         | 4.05125E+14             | 1.68   | 0.09                  | 0          |
| 735                                   | 90.172        | 0.90172     | 0.005355852         | 4.07881E+14             | 1.69   | 0.10                  | 0          |
| 730                                   | 90.164        | 0.90164     | 0.005365051         | 4.10675E+14             | 1.70   | 0.10                  | 0          |
| 725                                   | 90.157        | 0.90157     | 0.005373107         | 4.13507E+14             | 1.71   | 0.10                  | 0          |
| 720                                   | 90.143        | 0.90143     | 0.00538924          | 4.16378E+14             | 1.72   | 0.10                  | 0          |
| 715                                   | 90.121        | 0.90121     | 0.005414645         | 4.1929E+14              | 1.73   | 0.10                  | 0          |
| 710                                   | 90.12         | 0.9012      | 0.005415801         | 4.22243E+14             | 1.75   | 0.10                  | 0          |
| 705                                   | 90.137        | 0.90137     | 0.005396162         | 4.25238E+14             | 1.76   | 0.10                  | 0          |
| 700                                   | 90.137        | 0.90137     | 0.005396162         | 4.28275E+14             | 1.77   | 0.10                  | 0          |
| 695                                   | 90.144        | 0.90144     | 0.005388087         | 4.31356E+14             | 1.78   | 0.10                  | 0          |
| 690                                   | 90.175        | 0.90175     | 0.005352405         | 4.34482E+14             | 1.80   | 0.10                  | 0          |
| 685                                   | 90.215        | 0.90215     | 0.005306558         | 4.37653E+14             | 1.81   | 0.10                  | 0          |
| 680                                   | 90.253        | 0.90253     | 0.005263205         | 4.40871E+14             | 1.82   | 0.10                  | 0          |
| 675                                   | 90.262        | 0.90262     | 0.005252966         | 4.44137E+14             | 1.84   | 0.10                  | 0          |
| 670                                   | 90.277        | 0.90277     | 0.005235925         | 4.47451E+14             | 1.85   | 0.10                  | 0          |
| 665                                   | 90.32         | 0.9032      | 0.005187245         | 4.50816E+14             | 1.86   | 0.10                  | 0          |
| 660                                   | 90.353        | 0.90353     | 0.005150056         | 4.54231E+14             | 1.88   | 0.10                  | 0          |
| 655                                   | 90.384        | 0.90384     | 0.005115256         | 4.57698E+14             | 1.89   | 0.10                  | 0          |
| 650                                   | 90.392        | 0.90392     | 0.005106296         | 4.61219E+14             | 1.91   | 0.10                  | 0          |
| 645                                   | 90.396        | 0.90396     | 0.00510182          | 4.64795E+14             | 1.92   | 0.10                  | 0          |
| 640                                   | 90.381        | 0.90381     | 0.005118618         | 4.68426E+14             | 1.94   | 0.10                  | 0          |
| 635                                   | 90.331        | 0.90331     | 0.005174833         | 4.72114E+14             | 1.95   | 0.10                  | 0          |
| 630                                   | 90.308        | 0.90308     | 0.005200805         | 4.75861E+14             | 1.97   | 0.10                  | 0          |
| 625                                   | 90.312        | 0.90312     | 0.005196283         | 4.79668E+14             | 1.98   | 0.10                  | 0          |
| 620                                   | 90.373        | 0.90373     | 0.005127589         | 4.83536E+14             | 2.00   | 0.10                  | 0          |
| 615                                   | 90.379        | 0.90379     | 0.00512086          | 4.87467E+14             | 2.02   | 0.10                  | 0          |
| 610                                   | 90.347        | 0.90347     | 0.005156807         | 4.91463E+14             | 2.03   | 0.10                  | 0          |
| 605                                   | 90.302        | 0.90302     | 0.005207593         | 4.95525E+14             | 2.05   | 0.10                  | 0          |
| 600                                   | 90.262        | 0.90262     | 0.005252966         | 4.99654E+14             | 2.07   | 0.10                  | 0          |
| 595                                   | 90.222        | 0.90222     | 0.005298557         | 5.03853E+14             | 2.08   | 0.11                  | 0          |
| 590                                   | 90.182        | 0.90182     | 0.005344366         | 5.08123E+14             | 2.10   | 0.11                  | 0          |
| 585                                   | 90.14         | 0.9014      | 0.0053927           | 5.12466E+14             | 2.12   | 0.11                  | 0          |
| 580                                   | 90.086        | 0.90086     | 0.005455198         | 5.16884E+14             | 2.14   | 0.11                  | 0          |
| 575                                   | 90.031        | 0.90031     | 0.005519263         | 5.21378E+14             | 2.16   | 0.11                  | 0          |
| 570                                   | 89.972        | 0.89972     | 0.005588449         | 5.25952E+14             | 2.18   | 0.11                  | 0          |
| 565                                   | 89.903        | 0.89903     | 0.005669967         | 5.30606E+14             | 2.19   | 0.11                  | 0          |
| 560                                   | 89.838        | 0.89838     | 0.005747359         | 5.35344E+14             | 2.21   | 0.11                  | 0          |
| 555                                   | 89.76         | 0.8976      | 0.005840998         | 5.40167E+14             | 2.23   | 0.11                  | 0          |

|     |        |         |             |             |      |      |       |
|-----|--------|---------|-------------|-------------|------|------|-------|
| 550 | 89.677 | 0.89677 | 0.005941564 | 5.45077E+14 | 2.25 | 0.12 | 0     |
| 545 | 89.607 | 0.89607 | 0.006027121 | 5.50078E+14 | 2.27 | 0.12 | 0     |
| 540 | 89.54  | 0.8954  | 0.006109649 | 5.55171E+14 | 2.30 | 0.12 | 0     |
| 535 | 89.485 | 0.89485 | 0.006177864 | 5.6036E+14  | 2.32 | 0.12 | 0     |
| 530 | 89.415 | 0.89415 | 0.006265292 | 5.65646E+14 | 2.34 | 0.12 | 0     |
| 525 | 89.333 | 0.89333 | 0.006368581 | 5.71033E+14 | 2.36 | 0.12 | 0     |
| 520 | 89.261 | 0.89261 | 0.006460051 | 5.76524E+14 | 2.38 | 0.12 | 0     |
| 515 | 89.157 | 0.89157 | 0.006593461 | 5.82121E+14 | 2.41 | 0.13 | 0     |
| 510 | 89.056 | 0.89056 | 0.006724484 | 5.87828E+14 | 2.43 | 0.13 | 0     |
| 505 | 88.934 | 0.88934 | 0.006884676 | 5.93648E+14 | 2.46 | 0.13 | 0     |
| 500 | 88.829 | 0.88829 | 0.00702424  | 5.99585E+14 | 2.48 | 0.13 | 0     |
| 495 | 88.707 | 0.88707 | 0.007188376 | 6.05641E+14 | 2.50 | 0.13 | 0     |
| 490 | 88.573 | 0.88573 | 0.007371114 | 6.11821E+14 | 2.53 | 0.14 | 0     |
| 485 | 88.429 | 0.88429 | 0.00757037  | 6.18129E+14 | 2.56 | 0.14 | 0     |
| 480 | 88.292 | 0.88292 | 0.007762723 | 6.24568E+14 | 2.58 | 0.14 | 0     |
| 475 | 88.141 | 0.88141 | 0.007977892 | 6.31142E+14 | 2.61 | 0.14 | 0     |
| 470 | 87.964 | 0.87964 | 0.008234351 | 6.37856E+14 | 2.64 | 0.15 | 0     |
| 465 | 87.79  | 0.8779  | 0.00849095  | 6.44715E+14 | 2.67 | 0.15 | 0     |
| 460 | 87.576 | 0.87576 | 0.008812676 | 6.51723E+14 | 2.70 | 0.15 | 0     |
| 455 | 87.347 | 0.87347 | 0.009164505 | 6.58885E+14 | 2.72 | 0.16 | 0     |
| 450 | 87.085 | 0.87085 | 0.009576691 | 6.66205E+14 | 2.76 | 0.16 | 0     |
| 445 | 86.777 | 0.86777 | 0.010074543 | 6.73691E+14 | 2.79 | 0.17 | 0     |
| 440 | 86.411 | 0.86411 | 0.010685036 | 6.81346E+14 | 2.82 | 0.17 | 0     |
| 435 | 85.968 | 0.85968 | 0.011451763 | 6.89178E+14 | 2.85 | 0.18 | 0     |
| 430 | 85.466 | 0.85466 | 0.012357964 | 6.97192E+14 | 2.88 | 0.19 | 0     |
| 425 | 84.877 | 0.84877 | 0.013472739 | 7.05394E+14 | 2.92 | 0.20 | 0     |
| 420 | 84.14  | 0.8414  | 0.014947682 | 7.13792E+14 | 2.95 | 0.21 | 0     |
| 415 | 83.17  | 0.8317  | 0.017028309 | 7.22391E+14 | 2.99 | 0.23 | 0     |
| 410 | 81.889 | 0.81889 | 0.020027618 | 7.31201E+14 | 3.02 | 0.25 | 0     |
| 405 | 80.136 | 0.80136 | 0.024619303 | 7.40228E+14 | 3.06 | 0.27 | 0     |
| 400 | 77.592 | 0.77592 | 0.03235633  | 7.49481E+14 | 3.10 | 0.32 | 0     |
| 395 | 73.845 | 0.73845 | 0.046318913 | 7.58968E+14 | 3.14 | 0.38 | 0     |
| 390 | 68.326 | 0.68326 | 0.07341585  | 7.68699E+14 | 3.18 | 0.48 | 0.001 |
| 385 | 60.767 | 0.60767 | 0.126650015 | 7.78682E+14 | 3.22 | 0.64 | 0.001 |
| 380 | 51.52  | 0.5152  | 0.228096894 | 7.88928E+14 | 3.26 | 0.86 | 0.002 |
| 375 | 41.464 | 0.41464 | 0.413185329 | 7.99447E+14 | 3.31 | 1.17 | 0.004 |
| 370 | 31.725 | 0.31725 | 0.734669129 | 8.1025E+14  | 3.35 | 1.57 | 0.007 |
| 365 | 23.247 | 0.23247 | 1.267050159 | 8.21349E+14 | 3.40 | 2.07 | 0.013 |
| 360 | 16.676 | 0.16676 | 2.08170094  | 8.32757E+14 | 3.44 | 2.68 | 0.021 |
| 355 | 12.228 | 0.12228 | 3.15011612  | 8.44486E+14 | 3.49 | 3.32 | 0.031 |
| 350 | 9.492  | 0.09492 | 4.315053763 | 8.5655E+14  | 3.54 | 3.91 | 0.043 |
| 345 | 7.951  | 0.07951 | 5.328272168 | 8.68964E+14 | 3.59 | 4.38 | 0.053 |
| 340 | 7.013  | 0.07013 | 6.164681427 | 8.81743E+14 | 3.65 | 4.74 | 0.062 |
| 335 | 6.538  | 0.06538 | 6.680288654 | 8.94903E+14 | 3.70 | 4.97 | 0.067 |
| 330 | 6.34   | 0.0634  | 6.918135331 | 9.08462E+14 | 3.76 | 5.10 | 0.069 |
| 325 | 6.261  | 0.06261 | 7.017249737 | 9.22438E+14 | 3.81 | 5.17 | 0.07  |
| 320 | 6.256  | 0.06256 | 7.023607366 | 9.36851E+14 | 3.87 | 5.22 | 0.07  |
| 315 | 6.239  | 0.06239 | 7.045299824 | 9.51722E+14 | 3.94 | 5.27 | 0.07  |
| 310 | 6.271  | 0.06271 | 7.004565014 | 9.67072E+14 | 4.00 | 5.29 | 0.07  |
| 305 | 6.334  | 0.06334 | 6.925575905 | 9.82926E+14 | 4.07 | 5.31 | 0.069 |
| 300 | 6.448  | 0.06448 | 6.786582432 | 9.99308E+14 | 4.13 | 5.30 | 0.068 |
| 295 | 6.589  | 0.06589 | 6.621349917 | 1.01625E+15 | 4.20 | 5.28 | 0.066 |
| 290 | 6.731  | 0.06731 | 6.461971743 | 1.03377E+15 | 4.28 | 5.26 | 0.065 |
| 285 | 6.836  | 0.06836 | 6.348398841 | 1.0519E+15  | 4.35 | 5.26 | 0.063 |
| 280 | 6.902  | 0.06902 | 6.278787021 | 1.07069E+15 | 4.43 | 5.27 | 0.063 |
| 275 | 6.941  | 0.06941 | 6.238277972 | 1.09015E+15 | 4.51 | 5.30 | 0.062 |

|     |       |         |             |             |      |      |       |
|-----|-------|---------|-------------|-------------|------|------|-------|
| 270 | 6.972 | 0.06972 | 6.206403316 | 1.11034E+15 | 4.59 | 5.34 | 0.062 |
| 265 | 6.99  | 0.0699  | 6.188025823 | 1.13129E+15 | 4.68 | 5.38 | 0.062 |
| 260 | 6.979 | 0.06979 | 6.199245193 | 1.15305E+15 | 4.77 | 5.44 | 0.062 |
| 255 | 6.903 | 0.06903 | 6.277742582 | 1.17566E+15 | 4.86 | 5.52 | 0.063 |
| 250 | 6.757 | 0.06757 | 6.43351861  | 1.19917E+15 | 4.96 | 5.65 | 0.064 |
| 245 | 6.558 | 0.06558 | 6.657065694 | 1.22364E+15 | 5.06 | 5.80 | 0.067 |
| 240 | 6.358 | 0.06358 | 6.89589821  | 1.24914E+15 | 5.17 | 5.97 | 0.069 |
| 235 | 6.195 | 0.06195 | 7.10200002  | 1.27571E+15 | 5.28 | 6.12 | 0.071 |
| 230 | 6.071 | 0.06071 | 7.266230474 | 1.30345E+15 | 5.39 | 6.26 | 0.073 |
| 225 | 5.989 | 0.05989 | 7.378584172 | 1.33241E+15 | 5.51 | 6.38 | 0.074 |
| 220 | 5.928 | 0.05928 | 7.464187908 | 1.36269E+15 | 5.64 | 6.49 | 0.075 |
| 215 | 5.917 | 0.05917 | 7.479813156 | 1.39438E+15 | 5.77 | 6.57 | 0.075 |
| 210 | 5.959 | 0.05959 | 7.420464575 | 1.42758E+15 | 5.90 | 6.62 | 0.074 |
| 205 | 6.046 | 0.06046 | 7.300160533 | 1.4624E+15  | 6.05 | 6.64 | 0.073 |
| 200 | 6.149 | 0.06149 | 7.16214848  | 1.49896E+15 | 6.20 | 6.66 | 0.072 |

**Table 3: Impregnation 15%**

| 15% ZnTiO <sub>2</sub> (Impregnation) |               |             |                     |                         |        |                       |            |
|---------------------------------------|---------------|-------------|---------------------|-------------------------|--------|-----------------------|------------|
| wavelength                            | % Reflectance | Reflectance | $F(R)=(1-R)^2/(2R)$ | $v=c/\text{wavelength}$ | $E=hv$ | $\text{sqrt}(F(R)*E)$ | Absorbance |
| 800                                   | 97.893        | 0.97893     | 0.00022675          | 3.74741E+14             | 1.55   | 0.02                  | 0          |
| 795                                   | 97.903        | 0.97903     | 0.00022458          | 3.77097E+14             | 1.56   | 0.02                  | 0          |
| 790                                   | 97.894        | 0.97894     | 0.000226533         | 3.79484E+14             | 1.57   | 0.02                  | 0          |
| 785                                   | 97.94         | 0.9794      | 0.000216643         | 3.81901E+14             | 1.58   | 0.02                  | 0          |
| 780                                   | 97.903        | 0.97903     | 0.00022458          | 3.84349E+14             | 1.59   | 0.02                  | 0          |
| 775                                   | 97.842        | 0.97842     | 0.000237984         | 3.86829E+14             | 1.60   | 0.02                  | 0          |
| 770                                   | 97.812        | 0.97812     | 0.000244722         | 3.89341E+14             | 1.61   | 0.02                  | 0          |
| 765                                   | 97.8          | 0.978       | 0.000247444         | 3.91886E+14             | 1.62   | 0.02                  | 0          |
| 760                                   | 97.815        | 0.97815     | 0.000244044         | 3.94464E+14             | 1.63   | 0.02                  | 0          |
| 755                                   | 97.798        | 0.97798     | 0.000247899         | 3.97076E+14             | 1.64   | 0.02                  | 0          |
| 750                                   | 97.768        | 0.97768     | 0.000254778         | 3.99723E+14             | 1.65   | 0.02                  | 0          |
| 745                                   | 97.746        | 0.97746     | 0.000259884         | 4.02406E+14             | 1.66   | 0.02                  | 0          |
| 740                                   | 97.751        | 0.97751     | 0.000258719         | 4.05125E+14             | 1.68   | 0.02                  | 0          |
| 735                                   | 97.737        | 0.97737     | 0.000261987         | 4.07881E+14             | 1.69   | 0.02                  | 0          |
| 730                                   | 97.755        | 0.97755     | 0.000257789         | 4.10675E+14             | 1.70   | 0.02                  | 0          |
| 725                                   | 97.716        | 0.97716     | 0.000266929         | 4.13507E+14             | 1.71   | 0.02                  | 0          |
| 720                                   | 97.696        | 0.97696     | 0.00027168          | 4.16378E+14             | 1.72   | 0.02                  | 0          |
| 715                                   | 97.664        | 0.97664     | 0.000279371         | 4.1929E+14              | 1.73   | 0.02                  | 0          |
| 710                                   | 97.673        | 0.97673     | 0.000277197         | 4.22243E+14             | 1.75   | 0.02                  | 0          |
| 705                                   | 97.687        | 0.97687     | 0.000273832         | 4.25238E+14             | 1.76   | 0.02                  | 0          |
| 700                                   | 97.694        | 0.97694     | 0.000272158         | 4.28275E+14             | 1.77   | 0.02                  | 0          |
| 695                                   | 97.69         | 0.9769      | 0.000273114         | 4.31356E+14             | 1.78   | 0.02                  | 0          |
| 690                                   | 97.731        | 0.97731     | 0.000263394         | 4.34482E+14             | 1.80   | 0.02                  | 0          |
| 685                                   | 97.763        | 0.97763     | 0.000255934         | 4.37653E+14             | 1.81   | 0.02                  | 0          |
| 680                                   | 97.803        | 0.97803     | 0.000246762         | 4.40871E+14             | 1.82   | 0.02                  | 0          |
| 675                                   | 97.818        | 0.97818     | 0.000243366         | 4.44137E+14             | 1.84   | 0.02                  | 0          |
| 670                                   | 97.821        | 0.97821     | 0.00024269          | 4.47451E+14             | 1.85   | 0.02                  | 0          |
| 665                                   | 97.862        | 0.97862     | 0.000233545         | 4.50816E+14             | 1.86   | 0.02                  | 0          |
| 660                                   | 97.885        | 0.97885     | 0.000228494         | 4.54231E+14             | 1.88   | 0.02                  | 0          |
| 655                                   | 97.922        | 0.97922     | 0.000220486         | 4.57698E+14             | 1.89   | 0.02                  | 0          |
| 650                                   | 97.929        | 0.97929     | 0.000218987         | 4.61219E+14             | 1.91   | 0.02                  | 0          |
| 645                                   | 97.945        | 0.97945     | 0.000215581         | 4.64795E+14             | 1.92   | 0.02                  | 0          |
| 640                                   | 97.951        | 0.97951     | 0.000214311         | 4.68426E+14             | 1.94   | 0.02                  | 0          |
| 635                                   | 97.931        | 0.97931     | 0.00021856          | 4.72114E+14             | 1.95   | 0.02                  | 0          |
| 630                                   | 97.905        | 0.97905     | 0.000224147         | 4.75861E+14             | 1.97   | 0.02                  | 0          |
| 625                                   | 97.881        | 0.97881     | 0.000229368         | 4.79668E+14             | 1.98   | 0.02                  | 0          |
| 620                                   | 97.897        | 0.97897     | 0.000225881         | 4.83536E+14             | 2.00   | 0.02                  | 0          |
| 615                                   | 97.888        | 0.97888     | 0.000227839         | 4.87467E+14             | 2.02   | 0.02                  | 0          |
| 610                                   | 97.862        | 0.97862     | 0.000233545         | 4.91463E+14             | 2.03   | 0.02                  | 0          |
| 605                                   | 97.82         | 0.9782      | 0.000242916         | 4.95525E+14             | 2.05   | 0.02                  | 0          |
| 600                                   | 97.781        | 0.97781     | 0.000251785         | 4.99654E+14             | 2.07   | 0.02                  | 0          |
| 595                                   | 97.728        | 0.97728     | 0.0002641           | 5.03853E+14             | 2.08   | 0.02                  | 0          |
| 590                                   | 97.675        | 0.97675     | 0.000276715         | 5.08123E+14             | 2.10   | 0.02                  | 0          |
| 585                                   | 97.604        | 0.97604     | 0.000294087         | 5.12466E+14             | 2.12   | 0.02                  | 0          |
| 580                                   | 97.534        | 0.97534     | 0.000311745         | 5.16884E+14             | 2.14   | 0.03                  | 0          |
| 575                                   | 97.452        | 0.97452     | 0.000333103         | 5.21378E+14             | 2.16   | 0.03                  | 0          |
| 570                                   | 97.375        | 0.97375     | 0.000353819         | 5.25952E+14             | 2.18   | 0.03                  | 0          |
| 565                                   | 97.299        | 0.97299     | 0.000374896         | 5.30606E+14             | 2.19   | 0.03                  | 0          |
| 560                                   | 97.22         | 0.9722      | 0.00039747          | 5.35344E+14             | 2.21   | 0.03                  | 0          |
| 555                                   | 97.133        | 0.97133     | 0.000423115         | 5.40167E+14             | 2.23   | 0.03                  | 0          |

|     |        |         |             |             |      |      |       |
|-----|--------|---------|-------------|-------------|------|------|-------|
| 550 | 97.046 | 0.97046 | 0.000449587 | 5.45077E+14 | 2.25 | 0.03 | 0     |
| 545 | 96.95  | 0.9695  | 0.000479758 | 5.50078E+14 | 2.27 | 0.03 | 0     |
| 540 | 96.854 | 0.96854 | 0.00051094  | 5.55171E+14 | 2.30 | 0.03 | 0     |
| 535 | 96.776 | 0.96776 | 0.000537022 | 5.6036E+14  | 2.32 | 0.04 | 0     |
| 530 | 96.675 | 0.96675 | 0.000571793 | 5.65646E+14 | 2.34 | 0.04 | 0     |
| 525 | 96.565 | 0.96565 | 0.000610947 | 5.71033E+14 | 2.36 | 0.04 | 0     |
| 520 | 96.454 | 0.96454 | 0.000651819 | 5.76524E+14 | 2.38 | 0.04 | 0     |
| 515 | 96.332 | 0.96332 | 0.000698326 | 5.82121E+14 | 2.41 | 0.04 | 0     |
| 510 | 96.211 | 0.96211 | 0.000746096 | 5.87828E+14 | 2.43 | 0.04 | 0     |
| 505 | 96.063 | 0.96063 | 0.000806761 | 5.93648E+14 | 2.46 | 0.04 | 0     |
| 500 | 95.923 | 0.95923 | 0.00086642  | 5.99585E+14 | 2.48 | 0.05 | 0     |
| 495 | 95.753 | 0.95753 | 0.000941851 | 6.05641E+14 | 2.50 | 0.05 | 0     |
| 490 | 95.599 | 0.95599 | 0.001013023 | 6.11821E+14 | 2.53 | 0.05 | 0     |
| 485 | 95.419 | 0.95419 | 0.001099653 | 6.18129E+14 | 2.56 | 0.05 | 0     |
| 480 | 95.224 | 0.95224 | 0.001197712 | 6.24568E+14 | 2.58 | 0.06 | 0     |
| 475 | 95.01  | 0.9501  | 0.001310394 | 6.31142E+14 | 2.61 | 0.06 | 0     |
| 470 | 94.733 | 0.94733 | 0.001464183 | 6.37856E+14 | 2.64 | 0.06 | 0     |
| 465 | 94.456 | 0.94456 | 0.001626998 | 6.44715E+14 | 2.67 | 0.07 | 0     |
| 460 | 94.128 | 0.94128 | 0.001831569 | 6.51723E+14 | 2.70 | 0.07 | 0     |
| 455 | 93.768 | 0.93768 | 0.002070953 | 6.58885E+14 | 2.72 | 0.08 | 0     |
| 450 | 93.346 | 0.93346 | 0.002371591 | 6.66205E+14 | 2.76 | 0.08 | 0     |
| 445 | 92.863 | 0.92863 | 0.002742576 | 6.73691E+14 | 2.79 | 0.09 | 0     |
| 440 | 92.316 | 0.92316 | 0.003197921 | 6.81346E+14 | 2.82 | 0.09 | 0     |
| 435 | 91.67  | 0.9167  | 0.003784711 | 6.89178E+14 | 2.85 | 0.10 | 0     |
| 430 | 90.933 | 0.90933 | 0.004520388 | 6.97192E+14 | 2.88 | 0.11 | 0     |
| 425 | 90.047 | 0.90047 | 0.005500584 | 7.05394E+14 | 2.92 | 0.13 | 0     |
| 420 | 89.005 | 0.89005 | 0.006791193 | 7.13792E+14 | 2.95 | 0.14 | 0     |
| 415 | 87.706 | 0.87706 | 0.008616425 | 7.22391E+14 | 2.99 | 0.16 | 0     |
| 410 | 86.081 | 0.86081 | 0.011253271 | 7.31201E+14 | 3.02 | 0.18 | 0     |
| 405 | 83.972 | 0.83972 | 0.015296574 | 7.40228E+14 | 3.06 | 0.22 | 0     |
| 400 | 81.151 | 0.81151 | 0.021890353 | 7.49481E+14 | 3.10 | 0.26 | 0     |
| 395 | 77.26  | 0.7726  | 0.033465415 | 7.58968E+14 | 3.14 | 0.32 | 0     |
| 390 | 71.805 | 0.71805 | 0.055355339 | 7.68699E+14 | 3.18 | 0.42 | 0.001 |
| 385 | 64.427 | 0.64427 | 0.098207144 | 7.78682E+14 | 3.22 | 0.56 | 0.001 |
| 380 | 55.298 | 0.55298 | 0.180681833 | 7.88928E+14 | 3.26 | 0.77 | 0.002 |
| 375 | 45.096 | 0.45096 | 0.334225787 | 7.99447E+14 | 3.31 | 1.05 | 0.003 |
| 370 | 34.898 | 0.34898 | 0.607236862 | 8.1025E+14  | 3.35 | 1.43 | 0.006 |
| 365 | 25.742 | 0.25742 | 1.071061022 | 8.21349E+14 | 3.40 | 1.91 | 0.011 |
| 360 | 18.512 | 0.18512 | 1.793510735 | 8.32757E+14 | 3.44 | 2.49 | 0.018 |
| 355 | 13.536 | 0.13536 | 2.761533428 | 8.44486E+14 | 3.49 | 3.11 | 0.028 |
| 350 | 10.46  | 0.1046  | 3.832414723 | 8.5655E+14  | 3.54 | 3.68 | 0.038 |
| 345 | 8.693  | 0.08693 | 4.795219285 | 8.68964E+14 | 3.59 | 4.15 | 0.048 |
| 340 | 7.623  | 0.07623 | 5.597212468 | 8.81743E+14 | 3.65 | 4.52 | 0.056 |
| 335 | 7.039  | 0.07039 | 6.138476716 | 8.94903E+14 | 3.70 | 4.77 | 0.061 |
| 330 | 6.786  | 0.06786 | 6.402040816 | 9.08462E+14 | 3.76 | 4.90 | 0.064 |
| 325 | 6.691  | 0.06691 | 6.506179555 | 9.22438E+14 | 3.81 | 4.98 | 0.065 |
| 320 | 6.664  | 0.06664 | 6.5363212   | 9.36851E+14 | 3.87 | 5.03 | 0.065 |
| 315 | 6.647  | 0.06647 | 6.555425462 | 9.51722E+14 | 3.94 | 5.08 | 0.066 |
| 310 | 6.674  | 0.06674 | 6.525129065 | 9.67072E+14 | 4.00 | 5.11 | 0.065 |
| 305 | 6.735  | 0.06735 | 6.457579974 | 9.82926E+14 | 4.07 | 5.12 | 0.065 |
| 300 | 6.854  | 0.06854 | 6.329280213 | 9.99308E+14 | 4.13 | 5.11 | 0.063 |
| 295 | 7.013  | 0.07013 | 6.164681427 | 1.01625E+15 | 4.20 | 5.09 | 0.062 |
| 290 | 7.161  | 0.07161 | 6.018070047 | 1.03377E+15 | 4.28 | 5.07 | 0.06  |
| 285 | 7.272  | 0.07272 | 5.912047569 | 1.0519E+15  | 4.35 | 5.07 | 0.059 |
| 280 | 7.346  | 0.07346 | 5.843155265 | 1.07069E+15 | 4.43 | 5.09 | 0.058 |
| 275 | 7.39   | 0.0739  | 5.802849865 | 1.09015E+15 | 4.51 | 5.11 | 0.058 |

|     |       |         |             |             |      |      |       |
|-----|-------|---------|-------------|-------------|------|------|-------|
| 270 | 7.423 | 0.07423 | 5.772936097 | 1.11034E+15 | 4.59 | 5.15 | 0.058 |
| 265 | 7.443 | 0.07443 | 5.754936349 | 1.13129E+15 | 4.68 | 5.19 | 0.058 |
| 260 | 7.428 | 0.07428 | 5.768427022 | 1.15305E+15 | 4.77 | 5.24 | 0.058 |
| 255 | 7.347 | 0.07347 | 5.842233843 | 1.17566E+15 | 4.86 | 5.33 | 0.058 |
| 250 | 7.196 | 0.07196 | 5.984284614 | 1.19917E+15 | 4.96 | 5.45 | 0.06  |
| 245 | 6.995 | 0.06995 | 6.182937831 | 1.22364E+15 | 5.06 | 5.59 | 0.062 |
| 240 | 6.784 | 0.06784 | 6.404203019 | 1.24914E+15 | 5.17 | 5.75 | 0.064 |
| 235 | 6.61  | 0.0661  | 6.59734652  | 1.27571E+15 | 5.28 | 5.90 | 0.066 |
| 230 | 6.487 | 0.06487 | 6.740158139 | 1.30345E+15 | 5.39 | 6.03 | 0.067 |
| 225 | 6.401 | 0.06401 | 6.843284488 | 1.33241E+15 | 5.51 | 6.14 | 0.068 |
| 220 | 6.354 | 0.06354 | 6.900828861 | 1.36269E+15 | 5.64 | 6.24 | 0.069 |
| 215 | 6.34  | 0.0634  | 6.918135331 | 1.39438E+15 | 5.77 | 6.32 | 0.069 |
| 210 | 6.4   | 0.064   | 6.8445      | 1.42758E+15 | 5.90 | 6.36 | 0.068 |
| 205 | 6.497 | 0.06497 | 6.728344628 | 1.4624E+15  | 6.05 | 6.38 | 0.067 |
| 200 | 6.615 | 0.06615 | 6.591653987 | 1.49896E+15 | 6.20 | 6.39 | 0.066 |



**Table 4: Reflux 1:1mol ratio**

| 1:1 Zn-TiO <sub>2</sub> (Reflux) |               |             |                     |                         |        |                       |            |
|----------------------------------|---------------|-------------|---------------------|-------------------------|--------|-----------------------|------------|
| wavelength                       | % Reflectance | Reflectance | $F(R)=(1-R)^2/(2R)$ | $v=c/\text{wavelength}$ | $E=hv$ | $\text{sqrt}(F(R)*E)$ | Absorbance |
| 800                              | 90.239        | 0.90239     | 0.005279154         | 3.74741E+14             | 1.55   | 0.09                  | 0          |
| 795                              | 90.215        | 0.90215     | 0.005306558         | 3.77097E+14             | 1.56   | 0.09                  | 0          |
| 790                              | 90.164        | 0.90164     | 0.005365051         | 3.79484E+14             | 1.57   | 0.09                  | 0          |
| 785                              | 90.154        | 0.90154     | 0.005376562         | 3.81901E+14             | 1.58   | 0.09                  | 0          |
| 780                              | 90.134        | 0.90134     | 0.005399625         | 3.84349E+14             | 1.59   | 0.09                  | 0          |
| 775                              | 90.109        | 0.90109     | 0.00542853          | 3.86829E+14             | 1.60   | 0.09                  | 0          |
| 770                              | 90.108        | 0.90108     | 0.005429688         | 3.89341E+14             | 1.61   | 0.09                  | 0          |
| 765                              | 90.082        | 0.90082     | 0.005459843         | 3.91886E+14             | 1.62   | 0.09                  | 0          |
| 760                              | 90.096        | 0.90096     | 0.005443594         | 3.94464E+14             | 1.63   | 0.09                  | 0          |
| 755                              | 90.089        | 0.90089     | 0.005451716         | 3.97076E+14             | 1.64   | 0.09                  | 0          |
| 750                              | 90.082        | 0.90082     | 0.005459843         | 3.99723E+14             | 1.65   | 0.10                  | 0          |
| 745                              | 90.065        | 0.90065     | 0.005479611         | 4.02406E+14             | 1.66   | 0.10                  | 0          |
| 740                              | 90.085        | 0.90085     | 0.005456359         | 4.05125E+14             | 1.68   | 0.10                  | 0          |
| 735                              | 90.077        | 0.90077     | 0.005465653         | 4.07881E+14             | 1.69   | 0.10                  | 0          |
| 730                              | 90.071        | 0.90071     | 0.005472629         | 4.10675E+14             | 1.70   | 0.10                  | 0          |
| 725                              | 90.057        | 0.90057     | 0.005488926         | 4.13507E+14             | 1.71   | 0.10                  | 0          |
| 720                              | 90.044        | 0.90044     | 0.005504083         | 4.16378E+14             | 1.72   | 0.10                  | 0          |
| 715                              | 90.041        | 0.90041     | 0.005507584         | 4.1929E+14              | 1.73   | 0.10                  | 0          |
| 710                              | 90.034        | 0.90034     | 0.005515758         | 4.22243E+14             | 1.75   | 0.10                  | 0          |
| 705                              | 90.059        | 0.90059     | 0.005486597         | 4.25238E+14             | 1.76   | 0.10                  | 0          |
| 700                              | 90.08         | 0.9008      | 0.005462167         | 4.28275E+14             | 1.77   | 0.10                  | 0          |
| 695                              | 90.086        | 0.90086     | 0.005455198         | 4.31356E+14             | 1.78   | 0.10                  | 0          |
| 690                              | 90.121        | 0.90121     | 0.005414645         | 4.34482E+14             | 1.80   | 0.10                  | 0          |
| 685                              | 90.147        | 0.90147     | 0.005384628         | 4.37653E+14             | 1.81   | 0.10                  | 0          |
| 680                              | 90.166        | 0.90166     | 0.005362751         | 4.40871E+14             | 1.82   | 0.10                  | 0          |
| 675                              | 90.144        | 0.90144     | 0.005388087         | 4.44137E+14             | 1.84   | 0.10                  | 0          |
| 670                              | 90.137        | 0.90137     | 0.005396162         | 4.47451E+14             | 1.85   | 0.10                  | 0          |
| 665                              | 90.164        | 0.90164     | 0.005365051         | 4.50816E+14             | 1.86   | 0.10                  | 0          |
| 660                              | 90.192        | 0.90192     | 0.005332893         | 4.54231E+14             | 1.88   | 0.10                  | 0          |
| 655                              | 90.233        | 0.90233     | 0.005285998         | 4.57698E+14             | 1.89   | 0.10                  | 0          |
| 650                              | 90.259        | 0.90259     | 0.005256378         | 4.61219E+14             | 1.91   | 0.10                  | 0          |
| 645                              | 90.282        | 0.90282     | 0.005230252         | 4.64795E+14             | 1.92   | 0.10                  | 0          |
| 640                              | 90.276        | 0.90276     | 0.005237061         | 4.68426E+14             | 1.94   | 0.10                  | 0          |
| 635                              | 90.233        | 0.90233     | 0.005285998         | 4.72114E+14             | 1.95   | 0.10                  | 0          |
| 630                              | 90.204        | 0.90204     | 0.005319144         | 4.75861E+14             | 1.97   | 0.10                  | 0          |
| 625                              | 90.224        | 0.90224     | 0.005296272         | 4.79668E+14             | 1.98   | 0.10                  | 0          |
| 620                              | 90.289        | 0.90289     | 0.005222315         | 4.83536E+14             | 2.00   | 0.10                  | 0          |
| 615                              | 90.32         | 0.9032      | 0.005187245         | 4.87467E+14             | 2.02   | 0.10                  | 0          |
| 610                              | 90.314        | 0.90314     | 0.005194023         | 4.91463E+14             | 2.03   | 0.10                  | 0          |
| 605                              | 90.295        | 0.90295     | 0.005215517         | 4.95525E+14             | 2.05   | 0.10                  | 0          |
| 600                              | 90.283        | 0.90283     | 0.005229118         | 4.99654E+14             | 2.07   | 0.10                  | 0          |
| 595                              | 90.277        | 0.90277     | 0.005235925         | 5.03853E+14             | 2.08   | 0.10                  | 0          |
| 590                              | 90.259        | 0.90259     | 0.005256378         | 5.08123E+14             | 2.10   | 0.11                  | 0          |
| 585                              | 90.233        | 0.90233     | 0.005285998         | 5.12466E+14             | 2.12   | 0.11                  | 0          |
| 580                              | 90.196        | 0.90196     | 0.005328308         | 5.16884E+14             | 2.14   | 0.11                  | 0          |
| 575                              | 90.154        | 0.90154     | 0.005376562         | 5.21378E+14             | 2.16   | 0.11                  | 0          |
| 570                              | 90.103        | 0.90103     | 0.00543548          | 5.25952E+14             | 2.18   | 0.11                  | 0          |
| 565                              | 90.054        | 0.90054     | 0.005492422         | 5.30606E+14             | 2.19   | 0.11                  | 0          |
| 560                              | 90.007        | 0.90007     | 0.005547349         | 5.35344E+14             | 2.21   | 0.11                  | 0          |
| 555                              | 89.952        | 0.89952     | 0.00561201          | 5.40167E+14             | 2.23   | 0.11                  | 0          |

|     |        |         |             |             |      |      |       |
|-----|--------|---------|-------------|-------------|------|------|-------|
| 550 | 89.871 | 0.89871 | 0.005707995 | 5.45077E+14 | 2.25 | 0.11 | 0     |
| 545 | 89.79  | 0.8979  | 0.005804884 | 5.50078E+14 | 2.27 | 0.11 | 0     |
| 540 | 89.699 | 0.89699 | 0.005914815 | 5.55171E+14 | 2.30 | 0.12 | 0     |
| 535 | 89.632 | 0.89632 | 0.005996487 | 5.6036E+14  | 2.32 | 0.12 | 0     |
| 530 | 89.536 | 0.89536 | 0.006114596 | 5.65646E+14 | 2.34 | 0.12 | 0     |
| 525 | 89.441 | 0.89441 | 0.006232739 | 5.71033E+14 | 2.36 | 0.12 | 0     |
| 520 | 89.328 | 0.89328 | 0.00637491  | 5.76524E+14 | 2.38 | 0.12 | 0     |
| 515 | 89.189 | 0.89189 | 0.00655225  | 5.82121E+14 | 2.41 | 0.13 | 0     |
| 510 | 89.044 | 0.89044 | 0.006740147 | 5.87828E+14 | 2.43 | 0.13 | 0     |
| 505 | 88.873 | 0.88873 | 0.006965565 | 5.93648E+14 | 2.46 | 0.13 | 0     |
| 500 | 88.698 | 0.88698 | 0.007200568 | 5.99585E+14 | 2.48 | 0.13 | 0     |
| 495 | 88.484 | 0.88484 | 0.007493912 | 6.05641E+14 | 2.50 | 0.14 | 0     |
| 490 | 88.237 | 0.88237 | 0.007840711 | 6.11821E+14 | 2.53 | 0.14 | 0     |
| 485 | 87.956 | 0.87956 | 0.008246051 | 6.18129E+14 | 2.56 | 0.15 | 0     |
| 480 | 87.65  | 0.8765  | 0.008700656 | 6.24568E+14 | 2.58 | 0.15 | 0     |
| 475 | 87.314 | 0.87314 | 0.009215853 | 6.31142E+14 | 2.61 | 0.16 | 0     |
| 470 | 86.89  | 0.8689  | 0.009890212 | 6.37856E+14 | 2.64 | 0.16 | 0     |
| 465 | 86.411 | 0.86411 | 0.010685036 | 6.44715E+14 | 2.67 | 0.17 | 0     |
| 460 | 85.835 | 0.85835 | 0.011687961 | 6.51723E+14 | 2.70 | 0.18 | 0     |
| 455 | 85.193 | 0.85193 | 0.01286768  | 6.58885E+14 | 2.72 | 0.19 | 0     |
| 450 | 84.445 | 0.84445 | 0.014326368 | 6.66205E+14 | 2.76 | 0.20 | 0     |
| 445 | 83.594 | 0.83594 | 0.016099052 | 6.73691E+14 | 2.79 | 0.21 | 0     |
| 440 | 82.622 | 0.82622 | 0.018275694 | 6.81346E+14 | 2.82 | 0.23 | 0     |
| 435 | 81.522 | 0.81522 | 0.020941371 | 6.89178E+14 | 2.85 | 0.24 | 0     |
| 430 | 80.321 | 0.80321 | 0.02410721  | 6.97192E+14 | 2.88 | 0.26 | 0     |
| 425 | 78.984 | 0.78984 | 0.027959603 | 7.05394E+14 | 2.92 | 0.29 | 0     |
| 420 | 77.477 | 0.77477 | 0.032737814 | 7.13792E+14 | 2.95 | 0.31 | 0     |
| 415 | 75.766 | 0.75766 | 0.038756616 | 7.22391E+14 | 2.99 | 0.34 | 0     |
| 410 | 73.811 | 0.73811 | 0.046460807 | 7.31201E+14 | 3.02 | 0.37 | 0     |
| 405 | 71.49  | 0.7149  | 0.056848517 | 7.40228E+14 | 3.06 | 0.42 | 0.001 |
| 400 | 68.613 | 0.68613 | 0.071789877 | 7.49481E+14 | 3.10 | 0.47 | 0.001 |
| 395 | 64.865 | 0.64865 | 0.095156727 | 7.58968E+14 | 3.14 | 0.55 | 0.001 |
| 390 | 59.85  | 0.5985  | 0.134671888 | 7.68699E+14 | 3.18 | 0.65 | 0.001 |
| 385 | 53.273 | 0.53273 | 0.204926748 | 7.78682E+14 | 3.22 | 0.81 | 0.002 |
| 380 | 45.308 | 0.45308 | 0.330097871 | 7.88928E+14 | 3.26 | 1.04 | 0.003 |
| 375 | 36.523 | 0.36523 | 0.551615356 | 7.99447E+14 | 3.31 | 1.35 | 0.006 |
| 370 | 27.829 | 0.27829 | 0.935831909 | 8.1025E+14  | 3.35 | 1.77 | 0.009 |
| 365 | 20.157 | 0.20157 | 1.581312856 | 8.21349E+14 | 3.40 | 2.32 | 0.016 |
| 360 | 14.227 | 0.14227 | 2.585579366 | 8.32757E+14 | 3.44 | 2.98 | 0.026 |
| 355 | 10.236 | 0.10236 | 3.935900594 | 8.44486E+14 | 3.49 | 3.71 | 0.039 |
| 350 | 7.845  | 0.07845 | 5.412711297 | 8.5655E+14  | 3.54 | 4.38 | 0.054 |
| 345 | 6.508  | 0.06508 | 6.715391875 | 8.68964E+14 | 3.59 | 4.91 | 0.067 |
| 340 | 5.73   | 0.0573  | 7.75465349  | 8.81743E+14 | 3.65 | 5.32 | 0.078 |
| 335 | 5.331  | 0.05331 | 8.405758358 | 8.94903E+14 | 3.70 | 5.58 | 0.084 |
| 330 | 5.151  | 0.05151 | 8.732608038 | 9.08462E+14 | 3.76 | 5.73 | 0.087 |
| 325 | 5.098  | 0.05098 | 8.833257752 | 9.22438E+14 | 3.81 | 5.80 | 0.088 |
| 320 | 5.101  | 0.05101 | 8.827504608 | 9.36851E+14 | 3.87 | 5.85 | 0.088 |
| 315 | 5.086  | 0.05086 | 8.856338376 | 9.51722E+14 | 3.94 | 5.90 | 0.089 |
| 310 | 5.104  | 0.05104 | 8.821758245 | 9.67072E+14 | 4.00 | 5.94 | 0.088 |
| 305 | 5.144  | 0.05144 | 8.745782208 | 9.82926E+14 | 4.07 | 5.96 | 0.087 |
| 300 | 5.243  | 0.05243 | 8.56273989  | 9.99308E+14 | 4.13 | 5.95 | 0.086 |
| 295 | 5.359  | 0.05359 | 8.356893899 | 1.01625E+15 | 4.20 | 5.93 | 0.084 |
| 290 | 5.475  | 0.05475 | 8.159795091 | 1.03377E+15 | 4.28 | 5.91 | 0.082 |
| 285 | 5.56   | 0.0556  | 8.020605755 | 1.0519E+15  | 4.35 | 5.91 | 0.08  |
| 280 | 5.617  | 0.05617 | 7.92963387  | 1.07069E+15 | 4.43 | 5.93 | 0.079 |
| 275 | 5.652  | 0.05652 | 7.874686044 | 1.09015E+15 | 4.51 | 5.96 | 0.079 |

|     |       |         |             |             |      |      |       |
|-----|-------|---------|-------------|-------------|------|------|-------|
| 270 | 5.681 | 0.05681 | 7.829672383 | 1.11034E+15 | 4.59 | 6.00 | 0.078 |
| 265 | 5.704 | 0.05704 | 7.794298401 | 1.13129E+15 | 4.68 | 6.04 | 0.078 |
| 260 | 5.701 | 0.05701 | 7.798896159 | 1.15305E+15 | 4.77 | 6.10 | 0.078 |
| 255 | 5.647 | 0.05647 | 7.882493899 | 1.17566E+15 | 4.86 | 6.19 | 0.079 |
| 250 | 5.542 | 0.05542 | 8.049723713 | 1.19917E+15 | 4.96 | 6.32 | 0.08  |
| 245 | 5.4   | 0.054   | 8.286259259 | 1.22364E+15 | 5.06 | 6.48 | 0.083 |
| 240 | 5.249 | 0.05249 | 8.551868928 | 1.24914E+15 | 5.17 | 6.65 | 0.086 |
| 235 | 5.124 | 0.05124 | 8.783621561 | 1.27571E+15 | 5.28 | 6.81 | 0.088 |
| 230 | 5.037 | 0.05037 | 8.951728578 | 1.30345E+15 | 5.39 | 6.95 | 0.09  |
| 225 | 4.982 | 0.04982 | 9.061040068 | 1.33241E+15 | 5.51 | 7.07 | 0.091 |
| 220 | 4.959 | 0.04959 | 9.107472959 | 1.36269E+15 | 5.64 | 7.16 | 0.091 |
| 215 | 4.951 | 0.04951 | 9.123724905 | 1.39438E+15 | 5.77 | 7.25 | 0.091 |
| 210 | 5.016 | 0.05016 | 8.993182073 | 1.42758E+15 | 5.90 | 7.29 | 0.09  |
| 205 | 5.106 | 0.05106 | 8.817931097 | 1.4624E+15  | 6.05 | 7.30 | 0.088 |
| 200 | 5.234 | 0.05234 | 8.579093194 | 1.49896E+15 | 6.20 | 7.29 | 0.086 |

**Table 5: Reflux 1:2 mol ratio**

| 1:2 Zn-TiO <sub>2</sub> (Reflux) |               |             |                     |                         |        |                 |            |
|----------------------------------|---------------|-------------|---------------------|-------------------------|--------|-----------------|------------|
| wavelength                       | % Reflectance | Reflectance | $F(R)=(1-R)^2/(2R)$ | $v=c/\text{wavelength}$ | $E=hv$ | $\sqrt{F(R)*E}$ | Absorbance |
| 800                              | 97.69         | 0.9769      | 0.000273114         | 3.74741E+14             | 1.55   | 0.02            | 0          |
| 795                              | 97.675        | 0.97675     | 0.000276715         | 3.77097E+14             | 1.56   | 0.02            | 0          |
| 790                              | 97.627        | 0.97627     | 0.0002884           | 3.79484E+14             | 1.57   | 0.02            | 0          |
| 785                              | 97.643        | 0.97643     | 0.000284478         | 3.81901E+14             | 1.58   | 0.02            | 0          |
| 780                              | 97.595        | 0.97595     | 0.000296328         | 3.84349E+14             | 1.59   | 0.02            | 0          |
| 775                              | 97.523        | 0.97523     | 0.000314568         | 3.86829E+14             | 1.60   | 0.02            | 0          |
| 770                              | 97.461        | 0.97461     | 0.000330723         | 3.89341E+14             | 1.61   | 0.02            | 0          |
| 765                              | 97.397        | 0.97397     | 0.000347835         | 3.91886E+14             | 1.62   | 0.02            | 0          |
| 760                              | 97.362        | 0.97362     | 0.00035738          | 3.94464E+14             | 1.63   | 0.02            | 0          |
| 755                              | 97.322        | 0.97322     | 0.000368451         | 3.97076E+14             | 1.64   | 0.02            | 0          |
| 750                              | 97.264        | 0.97264     | 0.000384813         | 3.99723E+14             | 1.65   | 0.03            | 0          |
| 745                              | 97.229        | 0.97229     | 0.000394864         | 4.02406E+14             | 1.66   | 0.03            | 0          |
| 740                              | 97.189        | 0.97189     | 0.000406513         | 4.05125E+14             | 1.68   | 0.03            | 0          |
| 735                              | 97.16         | 0.9716      | 0.000415068         | 4.07881E+14             | 1.69   | 0.03            | 0          |
| 730                              | 97.121        | 0.97121     | 0.000426717         | 4.10675E+14             | 1.70   | 0.03            | 0          |
| 725                              | 97.054        | 0.97054     | 0.000447118         | 4.13507E+14             | 1.71   | 0.03            | 0          |
| 720                              | 96.985        | 0.96985     | 0.000468641         | 4.16378E+14             | 1.72   | 0.03            | 0          |
| 715                              | 96.935        | 0.96935     | 0.000484563         | 4.1929E+14              | 1.73   | 0.03            | 0          |
| 710                              | 96.895        | 0.96895     | 0.000497499         | 4.22243E+14             | 1.75   | 0.03            | 0          |
| 705                              | 96.86         | 0.9686      | 0.000508961         | 4.25238E+14             | 1.76   | 0.03            | 0          |
| 700                              | 96.819        | 0.96819     | 0.000522561         | 4.28275E+14             | 1.77   | 0.03            | 0          |
| 695                              | 96.761        | 0.96761     | 0.000542115         | 4.31356E+14             | 1.78   | 0.03            | 0          |
| 690                              | 96.733        | 0.96733     | 0.000551688         | 4.34482E+14             | 1.80   | 0.03            | 0          |
| 685                              | 96.683        | 0.96683     | 0.000568998         | 4.37653E+14             | 1.81   | 0.03            | 0          |
| 680                              | 96.625        | 0.96625     | 0.000589424         | 4.40871E+14             | 1.82   | 0.03            | 0          |
| 675                              | 96.558        | 0.96558     | 0.000613484         | 4.44137E+14             | 1.84   | 0.03            | 0          |
| 670                              | 96.472        | 0.96472     | 0.000645098         | 4.47451E+14             | 1.85   | 0.03            | 0          |
| 665                              | 96.419        | 0.96419     | 0.000664991         | 4.50816E+14             | 1.86   | 0.04            | 0          |
| 660                              | 96.365        | 0.96365     | 0.000685582         | 4.54231E+14             | 1.88   | 0.04            | 0          |
| 655                              | 96.327        | 0.96327     | 0.000700267         | 4.57698E+14             | 1.89   | 0.04            | 0          |
| 650                              | 96.284        | 0.96284     | 0.000717079         | 4.61219E+14             | 1.91   | 0.04            | 0          |
| 645                              | 96.254        | 0.96254     | 0.000728932         | 4.64795E+14             | 1.92   | 0.04            | 0          |
| 640                              | 96.214        | 0.96214     | 0.000744891         | 4.68426E+14             | 1.94   | 0.04            | 0          |
| 635                              | 96.132        | 0.96132     | 0.000778171         | 4.72114E+14             | 1.95   | 0.04            | 0          |
| 630                              | 96.031        | 0.96031     | 0.000820202         | 4.75861E+14             | 1.97   | 0.04            | 0          |
| 625                              | 95.938        | 0.95938     | 0.000859922         | 4.79668E+14             | 1.98   | 0.04            | 0          |
| 620                              | 95.877        | 0.95877     | 0.000886507         | 4.83536E+14             | 2.00   | 0.04            | 0          |
| 615                              | 95.79         | 0.9579      | 0.000925154         | 4.87467E+14             | 2.02   | 0.04            | 0          |
| 610                              | 95.691        | 0.95691     | 0.000970179         | 4.91463E+14             | 2.03   | 0.04            | 0          |
| 605                              | 95.567        | 0.95567     | 0.001028152         | 4.95525E+14             | 2.05   | 0.05            | 0          |
| 600                              | 95.451        | 0.95451     | 0.00108398          | 4.99654E+14             | 2.07   | 0.05            | 0          |
| 595                              | 95.319        | 0.95319     | 0.001149391         | 5.03853E+14             | 2.08   | 0.05            | 0          |
| 590                              | 95.163        | 0.95163     | 0.001229289         | 5.08123E+14             | 2.10   | 0.05            | 0          |
| 585                              | 94.986        | 0.94986     | 0.001323363         | 5.12466E+14             | 2.12   | 0.05            | 0          |
| 580                              | 94.766        | 0.94766     | 0.001445389         | 5.16884E+14             | 2.14   | 0.06            | 0          |
| 575                              | 94.534        | 0.94534     | 0.001580233         | 5.21378E+14             | 2.16   | 0.06            | 0          |
| 570                              | 94.284        | 0.94284     | 0.001732672         | 5.25952E+14             | 2.18   | 0.06            | 0          |
| 565                              | 94.052        | 0.94052     | 0.001880806         | 5.30606E+14             | 2.19   | 0.06            | 0          |
| 560                              | 93.846        | 0.93846     | 0.002017759         | 5.35344E+14             | 2.21   | 0.07            | 0          |
| 555                              | 93.616        | 0.93616     | 0.002176736         | 5.40167E+14             | 2.23   | 0.07            | 0          |

|     |        |         |             |             |      |      |       |
|-----|--------|---------|-------------|-------------|------|------|-------|
| 550 | 93.37  | 0.9337  | 0.002353909 | 5.45077E+14 | 2.25 | 0.07 | 0     |
| 545 | 93.127 | 0.93127 | 0.002536221 | 5.50078E+14 | 2.27 | 0.08 | 0     |
| 540 | 92.885 | 0.92885 | 0.002725048 | 5.55171E+14 | 2.30 | 0.08 | 0     |
| 535 | 92.673 | 0.92673 | 0.002896471 | 5.6036E+14  | 2.32 | 0.08 | 0     |
| 530 | 92.448 | 0.92448 | 0.003084583 | 5.65646E+14 | 2.34 | 0.08 | 0     |
| 525 | 92.218 | 0.92218 | 0.003283498 | 5.71033E+14 | 2.36 | 0.09 | 0     |
| 520 | 91.98  | 0.9198  | 0.003496434 | 5.76524E+14 | 2.38 | 0.09 | 0     |
| 515 | 91.705 | 0.91705 | 0.003751542 | 5.82121E+14 | 2.41 | 0.10 | 0     |
| 510 | 91.412 | 0.91412 | 0.004034139 | 5.87828E+14 | 2.43 | 0.10 | 0     |
| 505 | 91.089 | 0.91089 | 0.0043587   | 5.93648E+14 | 2.46 | 0.10 | 0     |
| 500 | 90.765 | 0.90765 | 0.004698134 | 5.99585E+14 | 2.48 | 0.11 | 0     |
| 495 | 90.392 | 0.90392 | 0.005106296 | 6.05641E+14 | 2.50 | 0.11 | 0     |
| 490 | 89.996 | 0.89996 | 0.005560248 | 6.11821E+14 | 2.53 | 0.12 | 0     |
| 485 | 89.56  | 0.8956  | 0.006084949 | 6.18129E+14 | 2.56 | 0.12 | 0     |
| 480 | 89.093 | 0.89093 | 0.006676319 | 6.24568E+14 | 2.58 | 0.13 | 0     |
| 475 | 88.582 | 0.88582 | 0.007358759 | 6.31142E+14 | 2.61 | 0.14 | 0     |
| 470 | 87.979 | 0.87979 | 0.008212439 | 6.37856E+14 | 2.64 | 0.15 | 0     |
| 465 | 87.305 | 0.87305 | 0.009229885 | 6.44715E+14 | 2.67 | 0.16 | 0     |
| 460 | 86.528 | 0.86528 | 0.010487633 | 6.51723E+14 | 2.70 | 0.17 | 0     |
| 455 | 85.649 | 0.85649 | 0.012022978 | 6.58885E+14 | 2.72 | 0.18 | 0     |
| 450 | 84.648 | 0.84648 | 0.01392141  | 6.66205E+14 | 2.76 | 0.20 | 0     |
| 445 | 83.493 | 0.83493 | 0.016317598 | 6.73691E+14 | 2.79 | 0.21 | 0     |
| 440 | 82.17  | 0.8217  | 0.019344584 | 6.81346E+14 | 2.82 | 0.23 | 0     |
| 435 | 80.661 | 0.80661 | 0.023183256 | 6.89178E+14 | 2.85 | 0.26 | 0     |
| 430 | 78.963 | 0.78963 | 0.028022958 | 6.97192E+14 | 2.88 | 0.28 | 0     |
| 425 | 77.011 | 0.77011 | 0.034312898 | 7.05394E+14 | 2.92 | 0.32 | 0     |
| 420 | 74.789 | 0.74789 | 0.042492514 | 7.13792E+14 | 2.95 | 0.35 | 0     |
| 415 | 72.244 | 0.72244 | 0.053318998 | 7.22391E+14 | 2.99 | 0.40 | 0.001 |
| 410 | 69.395 | 0.69395 | 0.067488005 | 7.31201E+14 | 3.02 | 0.45 | 0.001 |
| 405 | 66.173 | 0.66173 | 0.086460182 | 7.40228E+14 | 3.06 | 0.51 | 0.001 |
| 400 | 62.494 | 0.62494 | 0.112546807 | 7.49481E+14 | 3.10 | 0.59 | 0.001 |
| 395 | 58.24  | 0.5824  | 0.149716484 | 7.58968E+14 | 3.14 | 0.69 | 0.001 |
| 390 | 53.282 | 0.53282 | 0.204813213 | 7.68699E+14 | 3.18 | 0.81 | 0.002 |
| 385 | 47.595 | 0.47595 | 0.288505518 | 7.78682E+14 | 3.22 | 0.96 | 0.003 |
| 380 | 41.316 | 0.41316 | 0.416764916 | 7.88928E+14 | 3.26 | 1.17 | 0.004 |
| 375 | 34.592 | 0.34592 | 0.618380907 | 7.99447E+14 | 3.31 | 1.43 | 0.006 |
| 370 | 27.713 | 0.27713 | 0.942772412 | 8.1025E+14  | 3.35 | 1.78 | 0.009 |
| 365 | 21.205 | 0.21205 | 1.463959449 | 8.21349E+14 | 3.40 | 2.23 | 0.015 |
| 360 | 15.749 | 0.15749 | 2.25354975  | 8.32757E+14 | 3.44 | 2.79 | 0.023 |
| 355 | 11.824 | 0.11824 | 3.287807415 | 8.44486E+14 | 3.49 | 3.39 | 0.033 |
| 350 | 9.29   | 0.0929  | 4.428581324 | 8.5655E+14  | 3.54 | 3.96 | 0.044 |
| 345 | 7.794  | 0.07794 | 5.454161173 | 8.68964E+14 | 3.59 | 4.43 | 0.055 |
| 340 | 6.863  | 0.06863 | 6.319758684 | 8.81743E+14 | 3.65 | 4.80 | 0.063 |
| 335 | 6.387  | 0.06387 | 6.86033644  | 8.94903E+14 | 3.70 | 5.04 | 0.069 |
| 330 | 6.139  | 0.06139 | 7.175343966 | 9.08462E+14 | 3.76 | 5.19 | 0.072 |
| 325 | 6.058  | 0.06058 | 7.283839026 | 9.22438E+14 | 3.81 | 5.27 | 0.073 |
| 320 | 6.021  | 0.06021 | 7.334373394 | 9.36851E+14 | 3.87 | 5.33 | 0.073 |
| 315 | 6.007  | 0.06007 | 7.35365744  | 9.51722E+14 | 3.94 | 5.38 | 0.074 |
| 310 | 6.013  | 0.06013 | 7.345381814 | 9.67072E+14 | 4.00 | 5.42 | 0.073 |
| 305 | 6.055  | 0.06055 | 7.287913315 | 9.82926E+14 | 4.07 | 5.44 | 0.073 |
| 300 | 6.152  | 0.06152 | 7.158198231 | 9.99308E+14 | 4.13 | 5.44 | 0.072 |
| 295 | 6.281  | 0.06281 | 6.991920841 | 1.01625E+15 | 4.20 | 5.42 | 0.07  |
| 290 | 6.401  | 0.06401 | 6.843284488 | 1.03377E+15 | 4.28 | 5.41 | 0.068 |
| 285 | 6.496  | 0.06496 | 6.729524335 | 1.0519E+15  | 4.35 | 5.41 | 0.067 |
| 280 | 6.554  | 0.06554 | 6.661698898 | 1.07069E+15 | 4.43 | 5.43 | 0.067 |
| 275 | 6.59   | 0.0659  | 6.620203414 | 1.09015E+15 | 4.51 | 5.46 | 0.066 |

|     |       |         |             |             |      |      |       |
|-----|-------|---------|-------------|-------------|------|------|-------|
| 270 | 6.615 | 0.06615 | 6.591653987 | 1.11034E+15 | 4.59 | 5.50 | 0.066 |
| 265 | 6.635 | 0.06635 | 6.568970026 | 1.13129E+15 | 4.68 | 5.54 | 0.066 |
| 260 | 6.625 | 0.06625 | 6.580294811 | 1.15305E+15 | 4.77 | 5.60 | 0.066 |
| 255 | 6.563 | 0.06563 | 6.651282164 | 1.17566E+15 | 4.86 | 5.69 | 0.067 |
| 250 | 6.445 | 0.06445 | 6.790176901 | 1.19917E+15 | 4.96 | 5.80 | 0.068 |
| 245 | 6.288 | 0.06288 | 6.983093944 | 1.22364E+15 | 5.06 | 5.94 | 0.07  |
| 240 | 6.133 | 0.06133 | 7.18328199  | 1.24914E+15 | 5.17 | 6.09 | 0.072 |
| 235 | 5.998 | 0.05998 | 7.366102037 | 1.27571E+15 | 5.28 | 6.23 | 0.074 |
| 230 | 5.904 | 0.05904 | 7.498354688 | 1.30345E+15 | 5.39 | 6.36 | 0.075 |
| 225 | 5.852 | 0.05852 | 7.573347491 | 1.33241E+15 | 5.51 | 6.46 | 0.076 |
| 220 | 5.824 | 0.05824 | 7.614284835 | 1.36269E+15 | 5.64 | 6.55 | 0.076 |
| 215 | 5.846 | 0.05846 | 7.582086654 | 1.39438E+15 | 5.77 | 6.61 | 0.076 |
| 210 | 5.911 | 0.05911 | 7.488360617 | 1.42758E+15 | 5.90 | 6.65 | 0.075 |
| 205 | 6.02  | 0.0602  | 7.335747841 | 1.4624E+15  | 6.05 | 6.66 | 0.073 |
| 200 | 6.149 | 0.06149 | 7.16214848  | 1.49896E+15 | 6.20 | 6.66 | 0.072 |

**Table 6: Reflux 2:1 mol ratio**

| 2:1 Zn-TiO <sub>2</sub> (Reflux) |               |             |                     |                         |        |                 |            |
|----------------------------------|---------------|-------------|---------------------|-------------------------|--------|-----------------|------------|
| wavelength                       | % Reflectance | Reflectance | $F(R)=(1-R)^2/(2R)$ | $v=c/\text{wavelength}$ | $E=hv$ | $\sqrt{F(R)*E}$ | Absorbance |
| 800                              | 105.153       | 1.05153     | 0.001262608         | 3.74741E+14             | 1.55   | 0.04            | 0          |
| 795                              | 105.112       | 1.05112     | 0.001243081         | 3.77097E+14             | 1.56   | 0.04            | 0          |
| 790                              | 105.063       | 1.05063     | 0.001219933         | 3.79484E+14             | 1.57   | 0.04            | 0          |
| 785                              | 105.075       | 1.05075     | 0.001225583         | 3.81901E+14             | 1.58   | 0.04            | 0          |
| 780                              | 105.031       | 1.05031     | 0.001204928         | 3.84349E+14             | 1.59   | 0.04            | 0          |
| 775                              | 105.006       | 1.05006     | 0.001193267         | 3.86829E+14             | 1.60   | 0.04            | 0          |
| 770                              | 104.962       | 1.04962     | 0.001172874         | 3.89341E+14             | 1.61   | 0.04            | 0          |
| 765                              | 104.912       | 1.04912     | 0.001149904         | 3.91886E+14             | 1.62   | 0.04            | 0          |
| 760                              | 104.878       | 1.04878     | 0.001134408         | 3.94464E+14             | 1.63   | 0.04            | 0          |
| 755                              | 104.819       | 1.04819     | 0.001107755         | 3.97076E+14             | 1.64   | 0.04            | 0          |
| 750                              | 104.794       | 1.04794     | 0.001096553         | 3.99723E+14             | 1.65   | 0.04            | 0          |
| 745                              | 104.816       | 1.04816     | 0.001106408         | 4.02406E+14             | 1.66   | 0.04            | 0          |
| 740                              | 104.826       | 1.04826     | 0.001110902         | 4.05125E+14             | 1.68   | 0.04            | 0          |
| 735                              | 104.829       | 1.04829     | 0.001112251         | 4.07881E+14             | 1.69   | 0.04            | 0          |
| 730                              | 104.799       | 1.04799     | 0.001098789         | 4.10675E+14             | 1.70   | 0.04            | 0          |
| 725                              | 104.75        | 1.0475      | 0.001076969         | 4.13507E+14             | 1.71   | 0.04            | 0          |
| 720                              | 104.706       | 1.04706     | 0.001057553         | 4.16378E+14             | 1.72   | 0.04            | 0          |
| 715                              | 104.697       | 1.04697     | 0.001053603         | 4.1929E+14              | 1.73   | 0.04            | 0          |
| 710                              | 104.678       | 1.04678     | 0.001045286         | 4.22243E+14             | 1.75   | 0.04            | 0          |
| 705                              | 104.681       | 1.04681     | 0.001046597         | 4.25238E+14             | 1.76   | 0.04            | 0          |
| 700                              | 104.695       | 1.04695     | 0.001052726         | 4.28275E+14             | 1.77   | 0.04            | 0          |
| 695                              | 104.694       | 1.04694     | 0.001052287         | 4.31356E+14             | 1.78   | 0.04            | 0          |
| 690                              | 104.727       | 1.04727     | 0.001066799         | 4.34482E+14             | 1.80   | 0.04            | 0          |
| 685                              | 104.773       | 1.04773     | 0.001087185         | 4.37653E+14             | 1.81   | 0.04            | 0          |
| 680                              | 104.817       | 1.04817     | 0.001106857         | 4.40871E+14             | 1.82   | 0.04            | 0          |
| 675                              | 104.822       | 1.04822     | 0.001109103         | 4.44137E+14             | 1.84   | 0.05            | 0          |
| 670                              | 104.814       | 1.04814     | 0.001105511         | 4.47451E+14             | 1.85   | 0.05            | 0          |
| 665                              | 104.828       | 1.04828     | 0.001111801         | 4.50816E+14             | 1.86   | 0.05            | 0          |
| 660                              | 104.852       | 1.04852     | 0.001122625         | 4.54231E+14             | 1.88   | 0.05            | 0          |
| 655                              | 104.893       | 1.04893     | 0.001141232         | 4.57698E+14             | 1.89   | 0.05            | 0          |
| 650                              | 104.903       | 1.04903     | 0.001145792         | 4.61219E+14             | 1.91   | 0.05            | 0          |
| 645                              | 104.918       | 1.04918     | 0.001152649         | 4.64795E+14             | 1.92   | 0.05            | 0          |
| 640                              | 104.935       | 1.04935     | 0.001160443         | 4.68426E+14             | 1.94   | 0.05            | 0          |
| 635                              | 104.913       | 1.04913     | 0.001150361         | 4.72114E+14             | 1.95   | 0.05            | 0          |
| 630                              | 104.895       | 1.04895     | 0.001142143         | 4.75861E+14             | 1.97   | 0.05            | 0          |
| 625                              | 104.854       | 1.04854     | 0.00112353          | 4.79668E+14             | 1.98   | 0.05            | 0          |
| 620                              | 104.851       | 1.04851     | 0.001122173         | 4.83536E+14             | 2.00   | 0.05            | 0          |
| 615                              | 104.831       | 1.04831     | 0.001113152         | 4.87467E+14             | 2.02   | 0.05            | 0          |
| 610                              | 104.793       | 1.04793     | 0.001096106         | 4.91463E+14             | 2.03   | 0.05            | 0          |
| 605                              | 104.732       | 1.04732     | 0.001069006         | 4.95525E+14             | 2.05   | 0.05            | 0          |
| 600                              | 104.68        | 1.0468      | 0.00104616          | 4.99654E+14             | 2.07   | 0.05            | 0          |
| 595                              | 104.639       | 1.04639     | 0.001028313         | 5.03853E+14             | 2.08   | 0.05            | 0          |
| 590                              | 104.601       | 1.04601     | 0.001011902         | 5.08123E+14             | 2.10   | 0.05            | 0          |
| 585                              | 104.535       | 1.04535     | 0.0009837           | 5.12466E+14             | 2.12   | 0.05            | 0          |
| 580                              | 104.453       | 1.04453     | 0.000949193         | 5.16884E+14             | 2.14   | 0.05            | 0          |
| 575                              | 104.35        | 1.0435      | 0.000906684         | 5.21378E+14             | 2.16   | 0.04            | 0          |
| 570                              | 104.262       | 1.04262     | 0.000871106         | 5.25952E+14             | 2.18   | 0.04            | 0          |
| 565                              | 104.185       | 1.04185     | 0.000840535         | 5.30606E+14             | 2.19   | 0.04            | 0          |
| 560                              | 104.103       | 1.04103     | 0.000808555         | 5.35344E+14             | 2.21   | 0.04            | 0          |
| 555                              | 104.013       | 1.04013     | 0.000774142         | 5.40167E+14             | 2.23   | 0.04            | 0          |

|     |         |         |             |             |      |      |           |
|-----|---------|---------|-------------|-------------|------|------|-----------|
| 550 | 103.88  | 1.0388  | 0.000724605 | 5.45077E+14 | 2.25 | 0.04 | 0         |
| 545 | 103.741 | 1.03741 | 0.00067452  | 5.50078E+14 | 2.27 | 0.04 | 0         |
| 540 | 103.601 | 1.03601 | 0.000625824 | 5.55171E+14 | 2.30 | 0.04 | 0         |
| 535 | 103.497 | 1.03497 | 0.000590791 | 5.6036E+14  | 2.32 | 0.04 | 0         |
| 530 | 103.365 | 1.03365 | 0.00054773  | 5.65646E+14 | 2.34 | 0.04 | 0         |
| 525 | 103.23  | 1.0323  | 0.000505323 | 5.71033E+14 | 2.36 | 0.03 | 0         |
| 520 | 103.091 | 1.03091 | 0.000463391 | 5.76524E+14 | 2.38 | 0.03 | 0         |
| 515 | 102.939 | 1.02939 | 0.000419555 | 5.82121E+14 | 2.41 | 0.03 | 0         |
| 510 | 102.78  | 1.0278  | 0.000375968 | 5.87828E+14 | 2.43 | 0.03 | 0         |
| 505 | 102.599 | 1.02599 | 0.000329185 | 5.93648E+14 | 2.46 | 0.03 | 0         |
| 500 | 102.428 | 1.02428 | 0.000287772 | 5.99585E+14 | 2.48 | 0.03 | 0         |
| 495 | 102.217 | 1.02217 | 0.000240424 | 6.05641E+14 | 2.50 | 0.02 | 0         |
| 490 | 102.013 | 1.02013 | 0.00019861  | 6.11821E+14 | 2.53 | 0.02 | 0         |
| 485 | 101.77  | 1.0177  | 0.000153921 | 6.18129E+14 | 2.56 | 0.02 | 0         |
| 480 | 101.511 | 1.01511 | 0.000112457 | 6.24568E+14 | 2.58 | 0.02 | 0         |
| 475 | 101.224 | 1.01224 | 7.4003E-05  | 6.31142E+14 | 2.61 | 0.01 | 7.397E-07 |
| 470 | 100.885 | 1.00885 | 3.88177E-05 | 6.37856E+14 | 2.64 | 0.01 | 3.882E-07 |
| 465 | 100.497 | 1.00497 | 1.22894E-05 | 6.44715E+14 | 2.67 | 0.01 | 1.231E-07 |
| 460 | 100.053 | 1.00053 | 1.40376E-07 | 6.51723E+14 | 2.70 | 0.00 | 1.425E-09 |
| 455 | 99.538  | 0.99538 | 1.07217E-05 | 6.58885E+14 | 2.72 | 0.01 | 1.074E-07 |
| 450 | 98.94   | 0.9894  | 5.67819E-05 | 6.66205E+14 | 2.76 | 0.01 | 5.683E-07 |
| 445 | 98.232  | 0.98232 | 0.000159104 | 6.73691E+14 | 2.79 | 0.02 | 0         |
| 440 | 97.412  | 0.97412 | 0.000343784 | 6.81346E+14 | 2.82 | 0.03 | 0         |
| 435 | 96.445  | 0.96445 | 0.000655193 | 6.89178E+14 | 2.85 | 0.04 | 0         |
| 430 | 95.322  | 0.95322 | 0.001147882 | 6.97192E+14 | 2.88 | 0.06 | 0         |
| 425 | 93.993  | 0.93993 | 0.001919507 | 7.05394E+14 | 2.92 | 0.07 | 0         |
| 420 | 92.427  | 0.92427 | 0.003102466 | 7.13792E+14 | 2.95 | 0.10 | 0         |
| 415 | 90.559  | 0.90559 | 0.004921238 | 7.22391E+14 | 2.99 | 0.12 | 0         |
| 410 | 88.327  | 0.88327 | 0.007713323 | 7.31201E+14 | 3.02 | 0.15 | 0         |
| 405 | 85.608  | 0.85608 | 0.012097565 | 7.40228E+14 | 3.06 | 0.19 | 0         |
| 400 | 82.175  | 0.82175 | 0.01933256  | 7.49481E+14 | 3.10 | 0.24 | 0         |
| 395 | 77.707  | 0.77707 | 0.031977676 | 7.58968E+14 | 3.14 | 0.32 | 0         |
| 390 | 71.748  | 0.71748 | 0.055623537 | 7.68699E+14 | 3.18 | 0.42 | 0.001     |
| 385 | 64.046  | 0.64046 | 0.10091888  | 7.78682E+14 | 3.22 | 0.57 | 0.001     |
| 380 | 54.869  | 0.54869 | 0.185606368 | 7.88928E+14 | 3.26 | 0.78 | 0.002     |
| 375 | 44.891  | 0.44891 | 0.338264004 | 7.99447E+14 | 3.31 | 1.06 | 0.003     |
| 370 | 35.027  | 0.35027 | 0.602605237 | 8.1025E+14  | 3.35 | 1.42 | 0.006     |
| 365 | 26.175  | 0.26175 | 1.041094675 | 8.21349E+14 | 3.40 | 1.88 | 0.01      |
| 360 | 19.034  | 0.19034 | 1.722048218 | 8.32757E+14 | 3.44 | 2.44 | 0.017     |
| 355 | 14.058  | 0.14058 | 2.626983698 | 8.44486E+14 | 3.49 | 3.03 | 0.026     |
| 350 | 10.915  | 0.10915 | 3.635427038 | 8.5655E+14  | 3.54 | 3.59 | 0.036     |
| 345 | 9.084   | 0.09084 | 4.549603179 | 8.68964E+14 | 3.59 | 4.04 | 0.045     |
| 340 | 7.976   | 0.07976 | 5.308686419 | 8.81743E+14 | 3.65 | 4.40 | 0.053     |
| 335 | 7.385   | 0.07385 | 5.807405704 | 8.94903E+14 | 3.70 | 4.64 | 0.058     |
| 330 | 7.137   | 0.07137 | 6.041429711 | 9.08462E+14 | 3.76 | 4.76 | 0.06      |
| 325 | 7.051   | 0.07051 | 6.126447739 | 9.22438E+14 | 3.81 | 4.83 | 0.061     |
| 320 | 7.034   | 0.07034 | 6.143500964 | 9.36851E+14 | 3.87 | 4.88 | 0.061     |
| 315 | 7.007   | 0.07007 | 6.170756421 | 9.51722E+14 | 3.94 | 4.93 | 0.062     |
| 310 | 7.036   | 0.07036 | 6.141490404 | 9.67072E+14 | 4.00 | 4.96 | 0.061     |
| 305 | 7.13    | 0.0713  | 6.048272721 | 9.82926E+14 | 4.07 | 4.96 | 0.06      |
| 300 | 7.278   | 0.07278 | 5.906409236 | 9.99308E+14 | 4.13 | 4.94 | 0.059     |
| 295 | 7.457   | 0.07457 | 5.742394293 | 1.01625E+15 | 4.20 | 4.91 | 0.057     |
| 290 | 7.613   | 0.07613 | 5.605778122 | 1.03377E+15 | 4.28 | 4.90 | 0.056     |
| 285 | 7.732   | 0.07732 | 5.505292178 | 1.0519E+15  | 4.35 | 4.89 | 0.055     |
| 280 | 7.811   | 0.07811 | 5.440284036 | 1.07069E+15 | 4.43 | 4.91 | 0.054     |
| 275 | 7.863   | 0.07863 | 5.398211096 | 1.09015E+15 | 4.51 | 4.93 | 0.054     |



|     |       |         |             |             |      |      |       |
|-----|-------|---------|-------------|-------------|------|------|-------|
| 270 | 7.904 | 0.07904 | 5.365430931 | 1.11034E+15 | 4.59 | 4.96 | 0.054 |
| 265 | 7.93  | 0.0793  | 5.34482024  | 1.13129E+15 | 4.68 | 5.00 | 0.053 |
| 260 | 7.919 | 0.07919 | 5.353523526 | 1.15305E+15 | 4.77 | 5.05 | 0.054 |
| 255 | 7.84  | 0.0784  | 5.41675102  | 1.17566E+15 | 4.86 | 5.13 | 0.054 |
| 250 | 7.686 | 0.07686 | 5.543764374 | 1.19917E+15 | 4.96 | 5.24 | 0.055 |
| 245 | 7.475 | 0.07475 | 5.726338211 | 1.22364E+15 | 5.06 | 5.38 | 0.057 |
| 240 | 7.26  | 0.0726  | 5.923352342 | 1.24914E+15 | 5.17 | 5.53 | 0.059 |
| 235 | 7.082 | 0.07082 | 6.095562499 | 1.27571E+15 | 5.28 | 5.67 | 0.061 |
| 230 | 6.95  | 0.0695  | 6.228994604 | 1.30345E+15 | 5.39 | 5.79 | 0.062 |
| 225 | 6.874 | 0.06874 | 6.308155278 | 1.33241E+15 | 5.51 | 5.90 | 0.063 |
| 220 | 6.839 | 0.06839 | 6.345205382 | 1.36269E+15 | 5.64 | 5.98 | 0.063 |
| 215 | 6.83  | 0.0683  | 6.354794217 | 1.39438E+15 | 5.77 | 6.05 | 0.064 |
| 210 | 6.886 | 0.06886 | 6.295539498 | 1.42758E+15 | 5.90 | 6.10 | 0.063 |
| 205 | 6.987 | 0.06987 | 6.19108213  | 1.4624E+15  | 6.05 | 6.12 | 0.062 |
| 200 | 7.231 | 0.07231 | 5.950827936 | 1.49896E+15 | 6.20 | 6.07 | 0.06  |